Public knowledge, attitudes, and awareness of cyanobacterial health effects in Central Ontario, Canada

by

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Abstract

Cyanobacterial blooms are becoming more frequent and widespread, with potential health risks for people exposed to toxins through recreational water use. This study examined public knowledge of cyanobacteria and exposure prevention in the Simcoe/Muskoka region of Ontario, using mixed methods consisting of content analysis of 100 news media articles and survey responses from 110 participants. News media articles varied in quality; 33% explained how to identify a cyanobloom, and 49% provided advice on avoiding contact. The survey found that 71.8% of respondents primarily relied on news media for information. Participants expressed moderate concern about cyanobacteria (average rating 71.7/100), but 36.7% could not identify symptoms of cyanotoxin exposure, and 30% were unaware of cyanobloom signs. Among those who could identify cyanobloom signs, confidence was low (average rating 21/100).

Overall, while news media coverage lacked crucial illness-prevention details, the public showed some awareness of how to reduce exposure risks.

Keywords

Cyanobacteria, cyanoblooms, recreational water use, public health, cyanotoxin poisoning, water-related illness, Simcoe/Muskoka Ontario,

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Indigenous Land Acknowledgement Statement

I would like to acknowledge that the land on which this research was conducted is the traditional territory of the Anishinaabek Nation. I would also like to acknowledge the enduring presence of the Indigenous Peoples of this region, specifically, the Chippewa Tri – Council First Nations comprised of the Beausoleil First Nation, the Chippewas of Rama, and the Chippewas of Georgina Island. I also acknowledge the Moose Deer Point First Nation, the Wahta Mohawks, the Georgian Bay and Moon River Métis Councils in this region. It should be noted that the Wendat and the Haudenosaunee Nations have also walked on this territory.

I acknowledge the enduring presence of First Nation, Métis and Inuit people on this land and commit to moving forward in the spirit of reconciliation and respect.

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Preface

Access to clean water is essential for human health. Toxins from agriculture, industry, and residential run-off are well known for their damaging effects on the environment and human health (Drobac et al., 2013; Bennell et al., 2015). Bacterial loads in water bodies are a well-known environmental and health concern (Bennell et al., 2015). Toxins produced by aquatic species native to the waterbody are often overlooked as a health concern by the general public (Dellinger et al., 2017). Toxin producing cyanobacteria are found in most aquatic environments and large populations of organisms can create dangerous levels of toxins that can cause illnesses to exposed humans. The extensive variety of cyanobacteria and toxins they produce is variable and depends on multiple environmental factors including temperature, rainfall, and phosphorus loads (Qin et al., 2015). These characteristics have made it difficult to perform epidemiological studies of cyanobacterial induced illness whose results can be generalized to other locations or even to other bloom events. This has also made it difficult to predict and monitor cyanobacterial blooms to prevent exposures which could result in illness.

Cyanobacterial blooms are becoming more common, creating a greater risk of exposure and illness due to recreational activities involving contact with natural water bodies (Dellinger et al., 2017). Ontario has one of the largest freshwater reserves in the world and millions of lakes within the region (Dellinger et al., 2017). Many Ontarians commonly engage in water-related activities which could potentially put them in contact with toxic cyanobacteria. The potential for adverse health effects makes it is essential that public health officials and members of the public are adequately informed about the risks of cyanobacteria and how to avoid exposure.

Chapter 1

1. **Background**

1.1 Overview

Cyanobacteria are found in most aquatic environments and an imbalance allowing large populations of organisms to grow can create dangerous levels of toxins that can cause illnesses to exposed humans (Dellinger et al., 2017). Climate change may be causing cyanobacterial blooms to become more common, which may pose more serious risks of exposure to cyanobacteria through recreational water use (Dellinger et al., 2017). Ontario has one of the largest freshwater reserves in the world and millions of lakes within the region (Dellinger et al., 2017). A large number of Ontarians engage in recreational water activities during the summer months which contribute to the economy of the region and represents an important aspect of summer recreation in Ontario (County of Simcoe, 2014; County of Simcoe Economic Development Office, 2016; District of Muskoka, 2016). To date cyanoblooms have not been very common in Ontario with only a few waterbodies experiencing blooms regularly (Health Canada, 2012; Dellinger et al., 2017). Should cyanoblooms become more common it could pose a public health risk if current measures are not capable of coping with increased bloom frequency. This literature review aims to provide a brief overview of the current understanding of global trends in cyanobacteria prevalence, the health effects of cyanobacterial exposure, and the current procedures in Ontario for monitoring recreational waters in order to prevent exposures.

This research used the PubMed database for article collection as it represents a large collection of research on a wide range of health related topics from around the world. Articles were found using the title search keywords: ‘cyanobacteria’, ‘blue-green algae’, ‘cyanobacteria epidemiology’ and ‘blue-green algae epidemiology’ as these provided broad results for multiple types of studies which focused specifically on cyanobacteria and cyanobacteria related illness. The articles included in this review are some of the most relevant to the search terms and intended to represent an overview of the topic. This review is not exhaustive and is intended to provide a basis from which to direct further inquiries into this field.

1.2 Cyanobacteria Characteristics

Cyanobacteria, commonly referred to as blue-green algae, are categorized as Cyanophyceae; a diverse group of prokaryotic organisms that first appeared 2.3 billion years ago (Stewart et al., 2006a; Svircev et al., 2013). Cyanobacteria are notable for the number and variety of compounds that they produce, including multiple toxins, many of which are unique to cyanobacteria (Stewart et al., 2006a). Although cyanobacteria are found naturally in nearly all water bodies, overgrowth of cyanobacterial colonies can cause major environmental problems, and exposure to these toxins can cause adverse health events in animals and humans. A cyanobacterial overgrowth is commonly called a bloom, a cyanobloom, or a harmful algal bloom (HAB) (Almeida et al., 2012; Backer et al., 2015; McGregor et al., 2012). A bloom is often defined as a high cell density of greater than 20,000 cells per millilitre of water with the very large size of cyanobacterial cells differentiating a cyanobloom from other algal blooms (Graham et al., 2012). However; the definition of what cell concentration defines a bloom is not universally accepted. Aguilera and colleagues (2023) reviewed records of cyanoblooms in 295 waterbodies in 14 countries and found that there were thirteen different cell abundance thresholds and multiple arbitrary qualitative criteria that were used to define a bloom. The large differences in defining criteria between regions and blooms makes it difficult to compare bloom dynamics from different regions and time periods. Blooms are usually identified visually when they form dense surface scums or give the water a bright turquoise to green colour like paint spread across the surface. While these are the most common visual features, blooms do not always appear this way (Health Canada, 2012).

1.3 Causes of Cyanoblooms

There are multiple interacting factors, including eutrophication, water temperature, and water column stability, which contribute to the formation of bloom conditions, and ongoing research is being done to identify patterns of growth (Huber et al., 2012). Phosphorus and nitrogen are usually the limiting factors of cyanobacterial growth but eutrophication, the nutrient overloading of water bodies from anthropogenic activity, can provide enough excess nutrients for the cyanobacterial population to grow exponentially (Huber et al., 2012; Almeida et al., 2012). Cyanobacteria are able to grow under lower light and oxygen conditions than most other algae and plants (Almeida et al., 2012; Health Canada, 2012). Dense floating blooms limit oxygen exchange between air and water which can cause hypoxic or even anoxic conditions (Lee et al., 2015). Low oxygen conditions can eliminate aquatic plants, other algae, and even fish and other aquatic organisms thus contributing to the loss of ecological diversity (Lee et al., 2015). Ultimately, the increasing growth of cyanobacteria exacerbates the conditions which began the excessive growth initially leading to a feedback loop of increasing algal population along with the detrimental effects of such blooms (Almeida et al., 2012). Most species of cyanobacteria reach maximum growth rate at water temperatures between 20 ^{o}C and 25 ^{o}C, thus in Canada blooms are most common during the late summer to early fall months (Health Canada, 2012). Bloom season in Ontario is between June 1st and October 1st though some lakes may experience blooms well beyond the typical season (Wynn and Stumpf, 2015).

1.4 Global Warming and Cyanoblooms

Cyanobacterial blooms are more frequent and severe in warmer conditions which suggest that climate change trends will increase the frequency and severity of harmful bloom events (Huber et al., 2012; Stewart et al., 2006a; McGregor et al., 2012; Persuad et al., 2015). There has been a global increase in toxic cyanobacterial blooms over the past two centuries (Bertani et al., 2017). Analysis of sediment cores from 100 lakes in North America showed that cyanobacterial blooms have increased substantially and disproportionally to other phytoplankton since the industrial revolution (Huisman et al., 2018). Analysis of the sediments of the Baltic Sea have shown cyanoblooms occurring for thousands of years but blooms have become more common since the 1960s (Huisman et al., 2018). An extensive bloom was reported for the first time in the Mediterranean Sea in 2010 which represented an unprecedented northward expansion of the cyanobacterial bloom dynamics (Huisman et al., 2018). Lake Erie experienced significant blooms during the 1960s and early 1970s but through reductions in phosphorus loading the blooms were reduced during the 1980s and then saw a resurgence during the 1990s (Huisman et al., 2018). In 2011 high nutrient load conditions combined with a long warm summer resulted in a record-setting bloom that covered 5,000 sq km of Lake Erie (Huisman et al., 2018).

Pitois and colleagues (2016) used monitoring data from the region of Brittany in Western France to evaluate the trends in cyanobacterial growth patterns between the years of 2004 and 2011 (Pitois et al., 2016). The data showed a shift toward longer duration of cell densities higher than the alert levels defined by the World Health Organization (WHO) (Pitois et al., 2016).

Chapra and colleagues (2017) created a screening analysis of the contiguous United States' water bodies that included projections of climate change, greenhouse gas emissions, global atmospheric circulation, and cyanobacterial growth scenarios to create projections of cyanobacterial loads in the future. Their projections estimated that on average cyanobloom occurrences would increase from seven days per year per waterbody to 16 to 23 days per year by 2050, and 18 to 39 days per year by 2090 (Chapra et al., 2017).

Many studies have indicated that the occurrence of cyanobacterial blooms is likely to increase due to climate change and while there is evidence of increasing occurrences of blooms over previous decades, research conducted by Mishra and colleagues (2023) did not observe the expected overall increase in algal blooms in a very large sample of freshwater lakes in the contiguous United States between 2016 and 2020 when compared to 2008 and 2011 (Mishra et al., 2023). In most regions examined in the research, the occurrence of cyanoblooms was lower between 2016 and 2020 than it had been in 2008 through 2011 though regions which demonstrated the most significant temperature increases did see some increases in cyanoblooms (Mishra et al., 2023). The research suggested that the expected increase in bloom magnitude may be on a longer time scale than expected (Mishra et al., 2023). They concluded that the interplay of temperature, precipitation, land use, and agricultural practice required more nuanced ecosystem scale models to determine the impact of increased temperature on cyanobloom magnitude accurately (Mishra et al., 2023).

In addition to warmer conditions promoting cyanobloom formation, these conditions, along with more frequent blooms, may drive the selection of more toxigenic species and strains. (Qin et al., 2015; Svircev et al., 2012; Rastogi et al., 2015). On average, 60% of blooms have toxin producing abilities and some species even have some which produce toxins and some that do not, making it very difficult to identify toxic algae based on morphology alone (Lee et al., 2015; Health Canada, 2012).

Climate change also increases the frequency of extreme precipitation events which can increase fertilizer runoff, surface runoff that carries soil particles, and sewage treatment plant bypasses. All these increased flows add more nutrients to already overloaded lakes (Chapra, et al., 2017). Additionally, climate change may also increase drought periods, causing water in lakes and reservoirs to become warmer and stagnant: conditions that are also favourable to cyanobacterial blooms (Chapra et al., 2017).

Range expansion is of particular concern, as more strains and more toxic strains from tropical or subtropical regions may expand into more temperate areas (McGregor et al., 2012). This suggests that cyanobacteria may become a greater health risk in the future as blooms occur in waterbodies that have not experienced them before and exposing people who are not familiar with protection measures (Backer et al., 2015; Greenfield et al., 2014; Qin et al., 2015; Rastogi et al., 2015).

1.5 Tracking Cyanoblooms

There are several methods of tracking cyanoblooms and much research is being done to investigate methods of forecasting bloom dynamics. Most commonly in Ontario, blooms are tracked solely through visual inspection by an official from the Ministry of Natural Resources or the district health unit (Health Canada, 2012). The water may be tested if necessary but as testing is expensive and time consuming, tests may not be done frequently enough to adequately describe bloom characteristics, and results may not represent actual bloom conditions (Gong et al., 2022).

Other methods of tracking can include remote sensing buoys and satellite imaging of large areas (Gong et al., 2022; Kaloudis et al., 2022; Vaughan et al., 2022; Mutoti et al., 2023). However, these measures are currently expensive and are only worthwhile in areas that routinely experience large scale blooms annually (Gong et al., 2022). A cheaper method that is sometimes used to monitor for cyanobacteria in a water body is the measurement of total chlorophyll – a within the water column (Howard et al., 2021). It is hypothesized that higher levels of chlorophyll-a are correlated with higher levels of cyanobacteria (Howard et al., 2021). However this method may not actually be effective as Howard and colleagues (2021) found during a study of lakes in California that there was not a statistically significant correlation between chlorophyll-a and cyanobacteria in one lake which indicated that the technique is not always reliable (Howard et al., 2021). Given the dynamic interplay of factors in the development of cyanoblooms it is difficult, expensive, and time consuming to create forecasting methods which can adequately predict potential blooms. Predicting cyanoblooms can aid in the development of mitigation strategies in both the short term for seasonal changes and in the long term for interannual bloom dynamics. Prediction models can help target specific areas that require interventions proactively.

Some monitoring methods in development include the Sandwich Hybridization Assay, which measures target genes from a sample and can be used as *in situ* monitoring buoys or rapid on site assessment kits (Gong et al., 2022).Vaughan and colleagues (2022) proposed the use of artificial intelligence image recognition to quickly identify cyanobacterial cells in samples from *in situ* buoys for monitoring (Vaughan et al., 2022). Whitman and colleagues (2022) evaluated a satellite based Cyanobacterial Index (CI_{cyano}) algorithm for the monitoring of cyanoblooms and concluded that it could be an effective complementary method of tracking bloom dynamics in addition to in situ sampling methods (Whitman et al., 2022). These novel methods show promise as being effective and more cost effective than current monitoring methods but there is still development needed before they can be utilized on a large scale (Whitman et al., 2022; Gong et al., 2022; Vaughan et al., 2022)

1.6 Cyanobacterial Toxins

Cyanotoxins are secondary metabolites of cyanobacterial cells and are typically released during cell senescence and lysis though may also be released during cell growth (Pinto et al., 2023). Within cyanobacteria, cyanotoxins play a role in chemical defence against competing organisms, cellular nitrogen storage, DNA metabolism, chemical signalling, and contributing to cell homeostasis (Pinto et al., 2023). There are 46 known species of cyanobacteria are capable of producing toxins (Health Canada, 2012) but some estimates suggest that there may be as many as 2000 species of toxin producing cyanobacteria (Mutoti et al., 2023).

The cyanotoxins can be classified by compound type: cyclic peptides (i.e., microcystins, nodularins) alkaloids (i.e., anatoxin – a, and a(s), saxitoxins, cylindrospermopsin, aplysiatoxin, lyngbiatoxin – a) and lipopolysaccharides (Rastogi et al., 2015). Cyanotoxins may also be classified into functional groups based on their action in the body: hepatotoxins, neurotoxins, cytotoxins, dermatotoxins, and irritant toxins (Rastogi et al., 2015; Drobac et al., 2013; Stewart et al., 2006 a; Otten and Paerl 2015; Kaloudis et al., 2022). The CyanoMet Database has been recently developed and currently contains information for more than 2000 cyano-metabolites (Kaloudis et al., 2022). In addition to the vast number of distinct cyanotoxins there can be multiple structural variants of some of the toxins, for example, the microcystins which are the most common cyanotoxin have been found to have over 300 congeners (Reif et al., 2023). Cyanotoxin congeners refer to the structural variability found in a single type of toxin. Congeners may have the same component parts arranged in different ways that can affect their level of toxicity. Using the microcystin congenger MC-LR toxicity as a baseline (1.0), the MC-

RR toxicity levels have been found to range from 0.08 to 0.3, being less toxic and, MC-LW and MC-LFcongeners measuring as high as 7.0, being significantly more toxic (Chaffin et al., 2023). Water samples often contain a mixture of various congeners and the levels of nitrogen may affect the congeners that occur (Chaffin et al., 2023).

Cyanotoxins can affect the cellular system through: disorganization of the cytoskeleton, cell proliferation, genome damage, inhibition of enzyme activity, imprecise mitotic cell divisions, loss of membrane integrity, oxidative stress and lipid peroxidation (Rastogi et al., 2015). The tests used to determine toxicity of a cyanobacteria sample are time consuming and expensive, resulting in minimal testing of cyanoblooms, especially since bloom conditions and water movement can change rapidly throughout the day (Calado et al., 2017). Thus, for practicality within public health, most blooms are assumed to be toxic by default (Health Canada, 2012). Of the vast number of cyanotoxins produced, few have been studied in depth (Kaloudis et al., 2022).

1.7 Exposure Routes

Cyanotoxin poisoning can occur through multiple exposure routes including dermally and by inhalation, and ingestion (Lad et al., 2022; Mutoti et al., 2023; Reif et al., 2023). Dermal exposure can occur through direct contact with cyanotoxins in surface waters or scums (Otten and Paerl, 2015). Inhalation can occur from exposure to aerosolized water droplets from an affected waterbody which can occur with high speed boating or during very windy and wavy conditions but can also be created through water based activities such as vigorous play (Funari et al., 2017; Reif et al., 2023; Sun et al., 2023; Schaefer et al., 2020). Ingestion can occur through direct ingestion of the contaminated water through recreational activities or through contaminated drinking water (Otten and Paerl, 2015; Schaefer et al., 2020). Toxins can also be ingested through eating meat contaminated with cyanotoxins or ingesting plant products irrigated with contaminated water (Mutoti et al., 2023; Wolf et al., 2017).

Cyanobacterial contamination of drinking water is rare in developed countries (WHO, 2003; Health Canada, 2012; Qin et al., 2015). The intake pipes for drinking water treatment in developed countries are often far offshore and well below the thermocline, thereby avoiding water layers that cyanoblooms commonly inhabit (Svircev et al., 2013; Rastogi et al., 2015; Chapra et al., 2017). The filtration processes commonly used for drinking water can remove the cyanobacterial cells but not the toxins (Rastogi et al., 2015; Svircev et al., 2013). Reverse osmosis water treatment can reduce toxins but it is very costly, and may be only 60% effective (Chapra et al., 2017).

However, when drinking water is contaminated it can cause large scale exposures. In 1930 to 1931 approximately 9 000 people in the City of Charleston, Ohio were exposed to cyanotoxins through drinking water drawn from a bloom in the Ohio River (Wood, 2016).

Lake Erie is one of North America's most severely affected waterbodies; during 2014 nearly 500 000 residents of Toledo, Ohio lost access to drinking water during a cyanobloom as testing revealed toxins in their treated water (Chapra et al., 2017).

Recent research has indicated that ground water may also be contaminated with cyanotoxins when surface water containing the toxins recharge groundwater as soil is not effective at filtering out or degrading the toxins (Mutoti et al., 2023). Mutoti and colleagues note that groundwater makes up about 30% of all freshwater and is commonly extracted and used as drinking water with no treatment (Mutoti et al., 2023). There has been limited research into the amounts of cyanotoxins found in groundwater and some tests have shown concentrations of cyanotoxins exceeding guidelines for safe consumption which indicates that cyanotoxins in groundwater require more research and potentially a public health response (Mutoti et al., 2023).

Cyanotoxin exposure via inhalation also requires greater study as aerosols containing cyanotoxins can travel over 30km from the affected water sources and an individual may inhale over 11,000 litres of air per day on average (Lad et al., 2022). Microbes and algae ranging in size of 0.5 to 5 micrometers in size can be emitted from sea water and 10% can remain in the air for four days after emission and can travel up to 11000 km (Sun et al., 2023). The algal cells can then be inhaled and lodge in the nostrils and lungs in addition to the aerosolization of the cyanotoxins themselves (Sun et al., 2023). Inhalation of airborne algae and algal toxins may cause skin irritation and respiratory problems in humans (Sun et al., 2023). Inhalational intake of cyanotoxins has a lower median lethal dose than oral intake of cyanotoxin suggesting that inhalational intake may be more dangerous than oral intake (Sun et al., 2023). There has been minimal research into the effects of airborne cyanobacteria and cyanotoxins but in an epidemiological study of a cyanobloom in Florida in 2018 Reif and colleagues (2023) found that people who resided near the water but did not interact with the water directly still exhibited elevated respiratory illness and were found to have cyanotoxins present in nasal tissue swabs which researchers concluded were due to inhalation of aerosolized toxins.

In developed countries, the most common route of exposure to cyanobacteria is through water-based recreation such as swimming, wading, boating, surfing, etc. Wood (2016) estimated that half of all human exposures to cyanotoxins have been through recreational water use and Chapra and colleagues (2017) report that 46% (11 out of 24) of all reported recreational waterborne disease outbreaks in the U.S. in 2009 and 2010 were attributed to cyanobacteria.

The WHO designed a risk assessment categorization system for cyanotoxin exposure in recreational water according to low, moderate, high, and very high risk of illness (WHO, 2003). However, the guidelines have been criticized for not including standardized testing methods (Chorus and Bartram, 1999, Funari et al., 2017).

1.8 Cyanotoxin Poisoning

Cyanobacterial toxin poisoning (CTP) can cause multiple and highly varied symptoms depending on the type of toxin, route of exposure, amount of exposure, and sensitivity of the individual (Rastogi et al., 2015; Stewart et al.,2006a; Osborne et al., 2006). The lethal dose for 50% (LD50) of exposed humans for microcystin, one of the most common cyanotoxins, is 50 micrograms per kg compared to the 10,000 micrograms per kg for sodium cyanide (Wood, 2016). Cyanotoxins can act on the body within minutes to hours (Wood, 2017). The WHO concluded that there would be a high probability of adverse events from contact with cyanobacterial scums and a moderate probability of adverse events from contact with water with cell concentrations exceeding 100 000 cells per millilitre of water (Bacovic et al., 2020). Acute exposures can cause: headache, fever, sore throat, cough, myalgia, pneumonia, abdominal pain, vomiting, diarrhoea, dermatitis, blistering of the mouth, weakness, and muscle tremors (Stewart et al., 2006a; Osborne et al., 2006). Serious exposures can result in: kidney impairment, cirrhosis and liver damage, septic shock, paralysis, and impairment of immune function in animal models (Rastogi et al., 2015). Due to the wide range of symptoms it is often difficult to diagnose individuals as suffering from cyanobacterial toxin poisoning or allergic reactions to cyanobacteria exposure (Health Canada, 2012; Graham et al., 2008). Cyanobacterial blooms may also co-occur with elevated levels of fecal coliforms which can make it difficult to isolate the cause of illness. Metcalf and Codd (2020) suggest that cyanobacteria can be mutualist partners with non-phototrophic organisms and may engage in gene transfer. Recent research has suggested that cyanobacteria may act as reservoir for antibiotic resistant genes within the environment and may allow horizontal and vertical gene transmission with pathogenic bacteria though more research is needed (Volk and Lee, 2023; Wang et al., 2024).

There is also evidence to indicate that the extracellular materials of cyanobacterial blooms may host other pathogenic bacteria such as cholera (Metcalf and Codd, 2020). There is also concern that microplastics in the waterbody may affect the toxicity of cyanobacteria though much more research is needed to determine if this is the case (Metcalf and Codd, 2020).

The reaction to cyanobacterial antigens seems to be present in some people but not in others, suggesting that the reaction is at least partially related to an individual's susceptibility (Backovic et al., 2020). Backovic and colleagues (2020) concluded that approximately 20% of healthy individuals would develop a reaction to cyanobacteria extracts in the water, however; the sample sizes of the research were very small (Backovic et al., 2020). Using a skin prick method to test skin sensitivity resulted in 86% adverse reactions which may suggest that broken skin is more susceptible to the cyanobacterial toxins (Backovic et al., 2020).

There is no anti-toxin that can be used to treat cyanotoxin poisoning specifically; each of the symptoms must be treated with currently established methods (Health Canada, 2012). While there have been reports of extensive animal fatalities caused by cyanotoxins, there are very few confirmed human fatalities (Stewart et al., 2006a; Chorus and Bartram, 1999; Otten and Paerl, 2015). Most of the confirmed deaths from cyanobacterial exposures in human populations were caused by cyanotoxin contaminated water being used in kidney dialysis procedures (Health Canada, 2012; Lad et al., 2022; Mishra et al., 2023).

Most often acute cases of cyanobacterial exposure are not severe. Osborne and colleagues (2007) estimated a severe reaction rate of between 1.3 and 2.7% from exposure to a benthic cyanobacterium which have a lower risk to health than scum forming species (Graham et al., 2008). There have been very few epidemiological studies of the frequency and severity of cyanobacterial exposure associated illnesses. Given the wide range of variability in toxicity both between and within species, and between different bloom events, it is very difficult to make reliable predictions about the frequency and severity of illness that results from cyanobacterial exposure (Stewart et al., 2006a). In 2009 - 2010 the USA Centers of Disease Control (CDC) reported 11 disease outbreaks that were confirmed to be caused by cyanotoxins (Funari et al., 2017).

1.9 Long Term Exposure to Cyanotoxins

There is some indication that exposure to cyanobacterial toxins can both initiate and accelerate the growth of skin tumours (Backovic et al., 2020). Backovic and colleagues noted that in a population in Serbia there was a higher incidence of melanoma in areas around waterbodies which commonly experienced cyanobacteria blooms and they recommend additional research into the relationship between cyanobacterial exposure and increased cancer rates (Backovic et al., 2020). Lad and colleagues (2022) note that while there has been research into the effects of cyanotoxin exposure in otherwise healthy individuals, there is need to determine how pre-existing illness may affect susceptibility to cyanotoxin poisoning. Specifically, there is evidence that chronic cyanotoxin exposures that are far below the current acceptable limits can cause increased hepatic injury in individuals who have existing non-alcoholic fatty liver disease (NAFLD) (Lad et al., 2022). NAFLD affects approximately 75 to 92% of obese individuals in North America and there has been some research into the possibility that cyanotoxin exposure can contribute to the development of the disease there is minimal research into the effect of cyanotoxin exposure on those who have already developed the condition (Lad et al., 2022).

Lad and colleagues (2022) noted that cyanotoxin exposure was associated with overall impaired kidney function, gastrointestinal and colorectal carcinoma, and gastroenteritis but it is unclear whether cyanotoxins were a causative factor or simply exacerbated existing conditions.

1.10 Epidemiological Studies of Cyanotoxin Exposure

Of the few epidemiological studies of cyanobacterial exposure in recreational water, Pilotto and colleagues conducted the earliest known research in 1995 (Pilotto et al., 1997). The prospective cohort study included 852 participants who were approached while at beaches in South Australia. Participants exposed to more than 5 000 cells per millilitre for one hour were significantly more likely (OR=1.87; 95% CI = 0.68 – 1.54) to report symptoms commonly associated with cyanotoxin exposure seven days after exposure versus unexposed individuals. The researchers noted that allergic reactions may have accounted for some of the reported symptoms. The prospective cohort design was useful in approximating the prevalence of symptoms after exposure which could potentially be attributed to cyanobacterial exposure, but the study had a small control sample and variation in the exposure times and concentrations and potential confounding factors made it difficult to attribute symptoms to cyanobacteria with any surety.

Stewart and colleagues conducted a prospective cohort study of 1 331 respondents over a three-year period between 1999 and 2002 in southeast Queensland and central Florida (Stewart et al., 2006a). Participants were recruited at beach parking areas and asked to complete a survey before leaving. Participants were contacted by phone at approximately three days after exposure and interviewed about any symptoms. The surveys included information about chronic and recent acute illness and the severity. Water samples were also obtained on all study days and measured cyanobacterial cell surface area, and on some days, the presence of fecal coliforms. Individuals who were exposed to higher levels of cyanobacteria were more likely (OR=1.7; 95% CI 1.0–2.9) to report any symptom commonly caused by cyanobacteria exposure than those who were exposed to lower levels concentrations. The researchers noted that cyanobacterial cell concentrations remained low throughout the study. The lack of consistent sampling of fecal coliforms may have been confounding factors affecting their results.

Osborne and colleagues (2007) conducted a postal survey of 5 000 residents who lived in a marine area in Australia subject to annual cyanobacterial blooms (Osborne et al., 2007). They obtained a 27% response rate, with 78% of respondents reporting recreational activity in the affected waterbody. Of those who engaged in water based activity, 34% reported at least one symptom after, with 0.6% reporting the classic fever, respiratory, and rash symptoms of exposure to the cyanobacterial species that was in bloom. People who had knowledge of the cyanobacteria were less likely to report symptoms. The study may have been subject to recall bias as the survey asked about participants' experience over the previous seven months. Additionally, selection bias may have played a role with people who experienced symptoms being more likely to respond.

Svircev and colleagues (2013) conducted a longitudinal observational study of people in Serbia who were chronically exposed to cyanotoxins through drinking water. The researchers analyzed existing reports of incidence of multiple illnesses and compared results of exposed populations to unexposed populations. The mortality rate from primary liver cancer in the exposed regions was 11.6% as opposed to the unexposed regions which had a rate of 7.6%. They found a significant increase in the occurrence of primary liver cancer in exposed populations with no increased occurrence of the common risk factors for primary liver cancer; cirrhosis and hepatitis. As the study design was observational and utilized existing health care data, the study could not determine with certainty whether cyanobacteria was the cause of the increased prevalence or if there was an unknown confounding factor.

Lin and colleagues conducted a prospective cohort study of 15 726 participants at a beach in Puerto Rico in 2009 (Lin et al., 2016). Participants who had higher levels of exposure, taking into account cell density, duration of activity, and high risk behaviours including ingestion of water, were more likely to report any of the common symptoms of cyanotoxin poisoning than individuals with lower exposure. The researchers had 75% response rate which reduced the likelihood of selection bias.

Reif and colleagues (2023) conducted a prospective study of a total of 125 participants who were recruited during August and September of 2018 in the vicinity of the Lake Okeechobee and the St. Lucie River which were experiencing a bloom (Reif et al., 2023). Participants were invited to complete a questionnaire including their residential proximity to waterways, occupational, and recreational exposure details and a chronic illness assessment as well as indicating any symptoms that occurred within 10 days of exposure to the waterways and were asked to provide a nasal swab, urine sample, and blood sample in a single study visit (Reif et al., 2023). Surface water samples were obtained from waterways adjacent to the participant recruitment areas (Reif et al., 2023). Respiratory symptoms were reported by 93 (74.4%) participants, ocular symptoms reported by 62 (49.6%) participants, gastrointestinal symptoms were reported by 44 (35.2%) participants, headaches were reported by 54 (43%) participants and skin rash was reported by 13 (10%) participants (Reif et al., 2023). Participants with a history of respiratory illness including asthma and allergies were twice as likely to report respiratory symptoms (Reif et al., 2023). The mean symptom frequency did not decrease as the bloom dissipated and measured microcystin levels decreased (Reif et al., 2023). Reif and colleagues (2023) concluded that health effects were not limited to individuals who interact directly with affected waterbodies but also those who resided near them indicating that aerosolized toxins may pose a significant risk, particularly for individuals with pre-existing respiratory conditions.

1.11 Cyanotoxin Exposure Incidents and Case Studies

In 1979 there was an outbreak of hepatoenteritis in Palm Island Australia which caused 140 children and 10 adults to be hospitalized with symptoms including vomiting, headache, diarrhoea, and dehydration as well as acute kidney and liver damage (Lad et al., 2022). The outbreak was directly linked to the Solomon Dam reservoir which had been experiencing a cyanobacterial bloom that had been treated with the algaecide copper sulphate (Lad et al., 2022). The algaecide caused the cyanobacterial cells to lyse and release large amounts of the cyanotoxin cylindrospermopsin into the water supply (Lad et al., 2022).

In Caruaru, Brazil in 1996, 131 patients receiving haemodialysis were exposed to microcystins and cylindrospermopsin through the water used to prepare the dialysate (Lad et al., 2022). Of the 131 patients exposed, 116 developed symptoms consistent with cyanotoxin exposure and 100 of them developed acute liver failure and 76 died (Lad et al., 2022; Mishra et al., 2023).

Geh and colleagues (2016) described the case of an 11-year-old girl who had been exposed to cyanobacteria while playing in Lake Ontario, Canada. She had been playing with the cyanobacterial scum before applying sunscreen and swimming. During the night she developed a rash and blisters on her face, arms, and hands and became unconscious briefly after waking in the morning. In hospital, she was treated with diphenhydramine every 4 to 6 hours. The rash appeared to worsen as each dose wore off. On the third day after the exposure the rash worsened and she was returned to the hospital where she was prescribed oral corticosteroids. Eight days after exposure she experienced itching and blisters on her hands and was seen by an allergist who prescribed an epinephrine auto injector and topical corticosteroids. The rash and blisters completely resolved after ten days. Allergen testing confirmed that the girl had developed an allergy to cyanobacteria.

Vidal and colleagues presented a case study of a 20 month old child who had been exposed to cyanotoxins while swimming at a beach in Uruguay in 2015 (Vidal et al., 2017). The child had been exposed along with three adults who experienced gastrointestinal symptoms but recovered without intervention; the child however had to be hospitalized due to liver failure and ultimately required a liver transplant (Vidal et al., 2017). Analysis of the child's liver revealed that the damage had been caused by cyanotoxins (Vidal et al., 2017).

1.12 Long Term Health Effects of Cyanotoxin Exposure

In addition to the acute symptoms of cyanobacterial exposure, there is research suggesting that cyanotoxin exposure can contribute to neurodegenerative diseases and cancer initiation (Stewart et al., 2006a; Svircev et al., 2013; Chorus and Bartram, 1999; Rastogi et al., 2015; Health Canada, 2012; WHO, 2003). Microcystins, which are the most common cyanotoxin, have the potential to cause cancer initiation, and have been classified as a group 2B carcinogen by the International Agency for Research on Cancer (Drobac et al., 2013). Svircev and colleagues (2013) suggested that cyanotoxins acting as initiators or cofactors function synergistically with other risk factors to cause a higher incidence of primary liver cancer in chronically exposed populations. In animal models, acute exposures can cause liver damage which may initiate liver cancer but it is unclear as of yet whether acute exposures can cause similar effects in humans (Health Canada, 2012).

1.13 Measures for Combating Cyanoblooms

Cyanoblooms are difficult to control and once a bloom begins it exacerbates the conditions which gave rise to it (Almeida et al., 2012). Nutrient management, the reduction of excess nitrogen and phosphorus from runoff is the best long term solution but requires a coordinated effort from land owners and municipalities (Aranda et al., 2023; Anantapatula and Wilson, 2024). There are several existing methods for treating ongoing blooms but Anantapantula and Wilson concluded through meta-analysis that most *in situ* treatments for cyanoblooms did not significantly improve water quality by a number of measures including taste, smell, and appearance (Anantapantula and Wilson, 2024). Only four of the 18 tested chemical treatments and none of the tested bacterial, physical, or plant-based treatments produced any significant improvements in water quality (Anantapantula and Wilson, 2024). The best way of removing a bloom that is already in progress is to scoop up the thick surface scums through manual netting (Su et al., 2012; Qin et al., 2015). Manual removal of blooms results in lower toxin release than algaecides and also removes any pollutants that the cyanobacteria absorb (Su et al., 2012). While manual netting can be used to remove the scums and the intracellular toxins, it cannot remove the toxins that have already been released from the cells. Cyanotoxins are released most significantly when the bloom is dying and can remain in elevated concentrations in the water for more than 9 days at potentially hazardous levels, and up to 30 days at low concentrations,after the bloom has dissipated, making it difficult to determine how long a bloom may affect a waterbody through visual inspection (Wood, 2017; Greenfield et al., 2014).

There are no currently established treatments that are effective in removing toxins from surface waters (Mrdjen and Lee, 2018). A 2018 pilot study by Mrdjen and Lee used polypropylene to adsorb cyanotoxins for six days at a temperature of 65 ºC and there was on average a 70% reduction of the cyanotoxin microcystin congener MC-LR in the sample water (Mrdjen and Lee, 2018). It is hopeful that the findings of this study may be used to develop a quick response measure for the reduction of cyanotoxins in surface waters.

Dimitriou and colleagues (2016) found that use of hydrogen peroxide in small amounts could lower the levels of cyanotoxins in the water and in the cyanobacterial cells while not affecting the beneficial microorganisms within the lake.

Cyanophages are viruses that solely infect cyanobacteria and may represent a novel method to control cyanoblooms but more research is needed to develop a viable treatment (Aranda et al., 2023).

1.14 Guidelines for Cyanoblooms

The primary method for determining if a cyanobacterial bloom is present is visual inspection by searching for the large floating scums (Health Canada, 2012; Persuad, 2015; Graham et al., 2008). The Guidelines for Canadian Recreational Water Quality includes the Recreational Swimming Area Environmental Checklist that requires visual inspection of public beach areas (Health Canada, 2012). However, cyanobacterial blooms may not always be readily visible and toxin concentrations in the water can change very rapidly depending on the wind and water movement patterns (Graham et al., 2008; Greenfield et al., 2014). Additionally, the cyanotoxins can remain in the water for many days after a visible bloom has dissipated (Graham et al., 2008; Greenfield et al., 2014).

Funari and colleagues (2017) indicated that most of the guidelines around the world are informed by the WHO guidelines which were published in 2003. They also noted that the primary study that informed the WHO guidelines was limited to a single cyanotoxin which does not take into account the differing toxicities and concentrations of toxins that can be produced by cyanobacteria (Funari et al., 2017). Funari and colleagues (2017) also noted that the guidelines were developed with the assumption of exposures to an adult weighing approximately 60kg. A child may ingest the same amount of cyanotoxin as an adult but would result in a higher concentration of toxin per kilogram. They also noted that children are more likely to be exposed as adults will often avoid the visible signs of cyanobacterial blooms but children may play with scums or swim in blooms (Funari et al., 2017). Funari and colleagues (2017) also noted that basing the guidelines on the cell volume does not take into account the varying levels of toxin that could be produced by those cells or the amount of toxin that is in the water. They suggested that advancements in understanding of cyanobacteria in recent years should be taken into account and the WHO guidelines and those based from it including the Canadian guidelines should be revised.

Nielsen and Jiang (2020) noted that existing guidelines for cyanobacteria in recreational water only cover ingestion as the route of cyanobacterial exposure; however dermatological complaints are common with cyanobacterial exposure along with the physiochemical properties of cyanotoxins which suggest that the toxins may be penetrate human skin. The current understanding of dermal reaction to cyanobacterial exposure is that the cyanobacteria cause an allergic reaction or skin irritation in 5 to 15% of individuals (Neilsen and Jiang, 2020, Pilotto et al., 2004, Stewart et al., 2006). Neilsen and Jiang (2020) identified that many reports of illness are not consistent with the findings of dermal experiments and they argued that dermal penetration may be occurring. They suggested that the discrepancies noted were due to dermal penetration of cyanotoxins through the skin barrier and into the blood (Neilsen and Jiang, 2020).

Established guidelines also omit aerosolized exposure from their consideration. Plaas and Paerl (2021) concluded that both cyanobacterial cells and their toxins can be found in aerosolized water from waterbodies experiencing cyanoblooms but they advised that additional research is needed to determine what effects if any these aerosolized toxins may have on humans or the environment. Schaefer and colleagues (2020) conducted research around Lake Okeechobee, Florida which involved obtaining nasal swabs of people who worked or engaged in recreation on waters affected by a cyanobacterial bloom. They found that 95% of participants had detectable levels of the cyanotoxin microcystin in their nasal mucosa. Individuals who had close contact with the affected water body within the 24 hours prior to testing had the highest concentrations of microcystin (Schafer et al., 2020). The U.S. Environmental Protection Agency proposed new limits to microcystin exposure which would advocate limiting contact with waters that had concentrations of 8 ppb (Schafer et al., 2020). Schafer and colleagues found nasal concentrations that were well below the current acceptable limits for oral ingestion but there are no established limits for inhalational exposure (Schafer et al., 2020).

1.15 Conclusion

There are significant indications that the prevalence of cyanoblooms have increased since the industrial revolution and may increase even more rapidly due to the effects of climate change. Climatic changes are expected to cause cyanoblooms to become more frequent, more severe and more toxigenic and expand into areas that did not experience blooms before. Canada must prepare for this change by examining the current policies and procedures in place for cyanobacteria monitoring and response. The current Health Canada guidelines have been criticized for basing protocols on out of date and inadequate research which leaves risk for illness to occur in vulnerable individuals even if guidelines are followed correctly (Funari et al., 2017). The health effects of cyanobacterial exposures both acute and long term are still not fully known but given the current indications that cyanobacterial exposure may play a role in the initiation of serious long term illness it is essential that more research is conducted. Ontario in particular with its large number of highly utilized waterbodies could experience public health challenges should cyanoblooms become more common under guidelines that are not as effective as may be needed.

1.16 Research Question

The goal of this research is to inform the development of public health policy and education about the health risks of cyanobacteria. Stewart and colleagues (2006 b) noted that people frequently ignore beach closures due to cyanobacteria. However, Osborne and colleagues (2006) found that individuals who were aware of the health effects of cyanobacteria were less likely to report symptoms of exposure thus suggesting that effective education programs will help reduce cyanobacterial related illness. While the symptoms associated with exposure are most often acute and mild, there is the potential for more severe reactions and it has been suggested that cyanobacterial exposure may play a role in the etiology of severe long term illness including cancer and neurodegenerative disease (Stewart et al., 2006a; Svircev et al., 2013; Chorus and Bartram, 1999; Rastogi et al., 2015; Health Canada, 2012; WHO, 2003; Lad et al., 2023). The current trends in environmental conditions suggest that cyanobacterial blooms will become more common and severe in the future (Otten and Paerl, 2015; Stewart et al., 2006 a) such that it is important to develop programs to combat this emerging health concern.

This research aims to identify the knowledge, attitudes, and awareness of residents and visitors to Simcoe County and Muskoka District regarding the potential health effects of cyanobacterial exposure. The study also aims to determine the quality of the information that is provided in local news media which regard to the health effects of cyanobacterial exposure and measures that can be taken to avoid exposures.

1.17 Theoretical Framework

This research is based on the assumptions described in the Social Cognitive Theory (SCT) developed by Albert Bandura (Stajkovic and Luthans, 2002). The Social Cognitive Theory was first developed in the 1970s during a paradigm shift from focus of behaviour to a focus on cognition (Luszczynska and Schwarzer, 2005). The SCT is based on the premise that behavioural change is made possible by a personal sense of control; people who believe that they are able to control their actions to a desired end will attempt to do so (Luszczynska and Schwarzer, 2005). The SCT is based on the assumption of emergent interactive agency whereby the individual makes a causal contribution to their own motivations and actions within a system of triadic reciprocal causation (Bandura, 1989). Triadic reciprocal causation involves cognition, behaviour, personal factors, and environmental influences to operate as interacting determinants of behaviour (Bandura, 1989 a). Each source of influence may be given a different weight of regard depending on the individual (Bandura, 1989 a). Valuable knowledge is imparted within a social context (Bandura, 1989 a). In order for information to be retained and passed most efficiently, a suitable social context must be utilized. This concept is integral to the research goal of determining what social pathways (i.e., news media, peer relations, social media, district health unit bulletins, etc.) are providing the most accurate knowledge, the best retention, and the best behaviour results. The SCT will be used to investigate whether individuals see others modeling good avoidance behaviour or modeling a lack of avoidance behaviour when they are confronted with swimming advisories. This theory would allow for investigation of the interplay of modeled behaviours and understanding of the health impacts. For example, an individual arrives at a beach where a swim ban is in place but the person sees many other people ignoring the signs and engaging in water activities. This theory can provide the basis for evaluation of whether the individual will engage in the dangerous behaviour because they see others engaging in it without apparent consequences or whether they will refrain from engaging in potentially harmful exposure activities based on their own knowledge and affect. The SCT requires that individuals weigh the pros and cons of their own behaviour; thus it requires that individuals have adequate knowledge and experience to gauge the potential pros and cons. Individuals who are unaware of the health effects of cyanobacteria exposure will be unable to adequately weigh the risks of exposure. In order for someone to make an informed decision relating to their health behaviour they must have a full understanding of the risks that their behaviour poses and the necessary adjustments that will reduce their risk or improve their wellbeing.

1.18 Study Setting

The study location consists of Simcoe County and Muskoka District in South Central Ontario. The area is 11 333 square kilometers and has a permanent population of approximately 540 000 people and an estimated seasonal population increase of more than 170 300 people annually (County of Simcoe, 2014; District of Muskoka, 2016; County of Simcoe EDO, 2016). The region is a popular area with cottagers and tourists as there are more than 1 600 lakes within the region including a large portion of the Trent-Severn Waterway. The largest lakes in the region are the Southern tip of Georgian Bay, Lake Simcoe, and Lake Couchiching. Recreation from Lake

Simcoe alone generates over $200 million per year in the local economy (Lake Simcoe Region Conservation Authority, 2016).

1.19 Study Design - Overview

The study design was a convergent parallel mixed method design which used both quantitative and qualitative approaches, in order to gain a more complete understanding of the multiple factors that influence human decision making and health behaviours (Shoonenboom and Johnson, 2017). The qualitative portion consisted of a content analysis of news media articles about cyanobacteria. The quantitative part consisted of a cross-sectional survey of the general population about participants' knowledge of cyanobacteria and its potential health effects. The benefits of this design were that by analyzing both what people knew and what information they had available to them may reveal how effective educational information can be. The quantitative part of the study provided information about what participants knew, while the qualitative part analyzed the information that the participants received. In this way, any problem with dissemination of information, translation by the individual into understanding, and application could be identified and thus targeted more effectively, if improvements are needed.

1. Methods

1.20 News Media Evaluation

This research examines the role of news media, as it is the main source of cyanobacterial information for the public. In the study area of Simcoe County and Muskoka District of Ontario, Canada, news media are the primary dissemination method used by the district health units. This region was selected for study as it contains more than 1 600 lakes within the region including a large portion of the Trent-Severn Waterway. These water bodies are popular for recreational use by locals, cottagers, and visitors to the region. The area is 11 333 square kilometres and has a permanent population of approximately 540 000 people and an estimated seasonal population increase of more than 170 300 people annually (County of Simcoe, 2014; District of Muskoka, 2016; County of Simcoe EDO, 2016). Cottagers who live full time in the Greater Toronto Area which lies on the southern edge of the catchment area make up a large number of the seasonal visitors and are of particular interest because they spend large amounts of time and money on recreational water use within the region, while not consistently receiving the same news media as those who live within the region full time. There are few lakes in the region which experience annual cyanoblooms, but blooms have been becoming more frequent and severe recently (Bennell et al., 2015). These factors may lead to increased exposures in coming years. The region is served by many different news media organizations ranging from small local newspapers to large national news media conglomerates.

Online news media was chosen as the focus of this research as many print, radio, and television news media organizations also post their content on their own websites and online access has become more commonly used in recent years. Additionally, online searches have become a very popular way for people to find information about health and relevant news topics. Van de Waal and colleagues (2024) used internet search data as an analog for public awareness of cyanobacteria. For clarity, all individual stories, articles, bulletins, broadcasts, etc. will be referred to as news media articles regardless of their format. Articles meeting the study criteria were examined and evaluated based on a coding system developed by the researcher and informed by both academic literature and preliminary examinations of news media articles. The study focused solely on the information that was provided and not the way that it was delivered

1.21 News Media Inclusion and Exclusion Criteria

For an article to be included in the sample, cyanobacteria or blue-green algae had to be the primary focus of the article or incidence report. For example, an article reporting on the deaths of dogs exposed to cyanobacteria would qualify as the incident would not have occurred without the cyanobacterial bloom while an article that mentioned cyanobacteria as one of many threats to water quality with no further information would not be included as cyanobacteria was not a focus of the article.

The articles that were included had to be posted by a news media organization that includes the Simcoe/Muskoka area in its online distribution area, and that was defined by using the terms Simcoe, Simcoe Muskoka, or Muskoka in the search term. National and international stories were included as long as the media was commonly distributed in Simcoe/Muskoka through online presence. Articles that were posted by news media outlets located in the Greater Toronto Area (GTA) to the South of the study area were included because a large number of seasonal cottagers and visitors to the Simcoe/Muskoka area maintain their primary residence in the GTA. The GTA is the largest urban center in the province thus most provincial news is produced and distributed there. The research aimed to examine knowledge presented not only to those living full time in the study area, but also those who visit the study area, thus inclusion of the GTA was useful.

Articles published between January 1st 2013 and May 1st 2019 were eligible to be included in the sample. Articles that were not written in English were excluded. The first 100 articles to meet the criteria were included in the sample which corresponds to the 100 most relevant articles as deemed by the Google search engine.

1.23 Search Procedure

The news media articles were gathered using the Google search engine. The search terms used were: "blue-green algae Simcoe Muskoka", "blue-green algae Simcoe", "blue green algae Muskoka", "cyanobacteria Simcoe Muskoka", "cyanobacteria Muskoka", and "cyanobacteria Simcoe". These search terms were chosen as they were broad enough to encompass many articles about the topics using the most commonly known terminology while also targeting the specific area under consideration. These terms were sorted using the 'most relevant' sorting setting provided by Google which ranks results based on the number of times the search terms appear in the text or keywords of each result. The 'most relevant' sorting setting was used because it is the default setting that is most commonly used in searches by the general public. The goal was to find and include the articles that would be most easily and widely accessed by the general public. Thus, articles that were not carried by news media outlets or were behind pay walls were excluded as individuals are unlikely to read such articles in the course of normal browsing or casual searches. These methods were chosen because people who have not experienced a cyanobloom before are most likely to get information about cyanobacteria through routine casual browsing of news media and news media may be their first introduction to the threats that cyanobacteria can pose.

1.24 Coding

The coding key was designed to evaluate the article based on the presence or absence of key information items or topics. The criteria used in the coding can be found in Appendix A as well as the number of articles which met each criterion through presence or absence. Each information item was chosen because it is either a key piece of information for informing health behaviour decisions (e.g., description of a cyanobloom, route of exposure), or information that, while not necessary to health behaviour, aided in the understanding of cyanoblooms and their occurrences (e.g., causes of cyanoblooms, environmental impact of cyanoblooms). The coding key was entered into the Laurentian University REDCap survey tool for ease of use and efficient organization and storage of data. Each article was read and the data entered into REDCap as a checklist of the presence or absence of the key information. An information item was considered present if any mention at all had been made about the topic in the article. Information about the articles' title, source, focus location and type, were also recorded. Each article was assigned a score out of 100 based on the researcher's assessment of the quality of the article and its usefulness in providing information. The researcher read through each article once to determine if it met inclusion criteria, a second time to determine whether it met the evaluation criteria and a third time to confirm that all information had been taken into account, and entered accurately into the form. An associate re-coded a selection of articles to ensure that the coding procedures were valid. The associate drew the same conclusions from the articles that the researcher had and there was minimal discrepancy between the coding and the recoding.

1.25 Survey

The study involved completion of a short survey (Appendix B) of individuals who lived in, or visited, the Simcoe/Muskoka area, of South Central Ontario, Canada which boasts a large tourism industry which focuses heavily on waterways. Surveys were delivered both online, through direct input by the participant into the survey form hosted by Laurentian University's secure REDCap server (Harris et al., REDCap 2009) or in person, on paper copies, at the Orillia Farmers' Market or at the Barrie Farmers' Market that were then input into the online survey form by the researcher. Participants were invited to complete the survey online through social media posts or by email with the email addresses being solicited in person. Participants were also offered the option of completing a paper copy of the survey which would then be transcribed to the online server. This method allowed for a larger sample while also accommodating individuals who were not comfortable using computers.

1.26 Theoretical Design of Survey Questions

Survey questions were informed by the literature based on the Social Cognitive Theory developed by Bandura (Bandura, 1989). The Social Cognitive Theory is based on the premise that behavioural change is made possible by a personal sense of control; people who believe that they are able to control their actions to a desired end will attempt to do so (Luszczynska and Schwarzer, 2005). The core concepts of knowledge, self-efficacy, outcome expectations, goals, and facilitators/impediments represent factors that affect how a person makes a decision about engaging in a behaviour that can affect their health. The survey (Appendix B) consisted of 42 questions in multiple choice, true and false, short answer, sliding scale, and drop down menu questions. The questions determined the demographic characteristics of the sample, experience with cyanobacterial illness, level of concern about general and specific aspects of water quality, level of knowledge about cyanobacterial illness prevention confidence, and attitudes about people who engage in behaviours that risk exposure and associated inclinations in that situation. Level of concern questions assessed knowledge about certain aspects of water quality.

1.27 Survey Inclusion/Exclusion Criteria

Inclusion criteria for the survey targeted a diversity of adults. Individuals who lived in, or visited the Simcoe/Muskoka area, who could read and write in English, and were 16 years of age or older, were eligible to participate. Individuals who did not live in or visit the Simcoe/Muskoka area were not included as they were unlikely to participate in regional recreational water use. It was important to include visiting non-residents in the survey as the study area is popular with cottagers and tourists who could have differing knowledge from residents. The survey was offered in English as it is the language most commonly spoken in the area. Children under the age of 16 were not included as they would likely be under the supervision of a parent or guardian and may not make their own decisions about whether a water body was safe for swimming.

1.28 Recruitment

Participants were recruited using snowball sampling for ease of recruitment. Online recruitment was initiated through friends, family, and social groups (The Orillia Jubilee Chorale and The Base Borden Volunteer Brass and Reed Band) of the researcher who were invited to participate in the survey through direct email, social media links, or paper copies of the survey and were also invited to pass on the link to their own friends and family. Social media recruitment, consisting of a recruitment poster and link to the online survey, were posted on the researcher's personal social media pages (Facebook and Instagram) as well as pages of local cities and parks, to gain a more diverse sample. Participant recruitment began on September 21st 2018 and concluded on March 31st 2019. In person recruitment included five six hour sessions of recruiting participants at two popular year round Farmers Markets located in Barrie and Orillia. A table set up within each market displayed the same recruitment posters used online and a slideshow of images of cyanoblooms. The researcher and assistant staffed the table at all times during the six hour sessions and were available to explain the goals of the study and participation. Participants completed a paper copy of the survey at the market table or took a paper slip with the study information and a link to the online survey tool. At three of the five sessions, candies and small baked goods were offered for free to all people who came to the table, regardless of their eligibility or participation in the study.

1.29 Survey Data

Surveys completed on paper were entered by the researcher into the REDCap (version 9.1.0: Harris et al., REDCap 2009) survey portal and each were assigned a number so that rechecking could be performed by an associate. All data were double checked for accuracy by the researcher at the time of initial input and a random selection of ten surveys were later rechecked by an associate and the results were compared. The comparison revealed an error rate of less than 4%. Data were kept on the secure Laurentian REDCap (Harris et al., REDCap 2009) server with no individual identifying information.

1.30 Reflexivity

The researcher has endeavoured to reduce bias as much as possible while researching and writing this study. I would like to make note of pre-existing beliefs that I am aware of and have tried to consciously mitigate any bias that this may have imparted into my work.

In a broad sense I wanted to research this topic because it is of particular interest to me as someone who has participated in open water swimming events, some of them occurring during a swimming advisory for elevated fecal coliforms. Prior to this research I did not know very much about cyanobacteria or the associated health risks even though I was a member of a demographic that was very likely to be exposed to cyanobacteria through my recreational activities. I wanted learn more about a potential threat to my community and use my research to benefit my own community and others around the world.

Commencing this research I had an inclination to believe that cyanobacterial blooms were potentially more severe and damaging to health and environment than has been demonstrated in the literature. In reading the literature and finding information that both showed how dangerous cyanobacteria can be but also how limited the recorded instances of illness and injuries are. I had to be careful that I was not overstating how common illness actually is when speaking with study participants and in writing this document. At the same time, with the literature indicating that cyanoblooms are likely to increase and the challenges in monitoring cyanoblooms, and advising the public of a potential health impact I wanted to make sure that I was not understating the potential threat to health that cyanoblooms pose as they become more common.

Additionally, having read the literature and taken the common consensus of increasing cyanobloom frequency to heart, I had to be careful that I was not discounting research findings that did not align with the common consensus. Specifically, in reading the study by Mishra and colleagues (2023) which found that cyanobloom occurrence had actually decreased during the study period I felt tempted to leave the research out of my literature review because if blooms were not increasing then maybe my research was not necessary. However; it was important to present even data that does not necessarily align with the common consensus because it shows that there are nuances to the data that would be otherwise lost if the bias had not been checked. The research of Mishra and colleagues presents a potentially optimistic view, but also one that takes into account the many intertwining factors that play a role in the occurrence of cyanoblooms. Mishra and colleagues also made note that their findings were not what would have been expected by the current consensus but that the results did not necessarily refute the consensus but added more nuance and complexity.

Because I belong to the community that I studied, in broad terms my personal interests would align with bettering the community. I want to be able to make a positive impact on the health and wellbeing of those in my community. This background had the potential for me to display a bias toward making my research more impactful and justify providing additional supports to my community. I have endeavoured to be as fair in this aspect as possible and note that information that could benefit my community could also be of significance to many other regions.

References

Aguilera, A., Almanza, V. Haakonsson, S., Palacio, H., Benitez Rodas, G., Barros, M., Capelo-Neto, J., Urrutia, R., Aubriot, L., and Bonilla, S. (2023) Cyanobacterial bloom monitoring and assessment in Latin America. *Harmful Algae*. 125. 102429.

Almeida, C., Gonzalez, S., Mallea, M., Gonzalez, P. (2012) A recreational water quality index using chemical, physical, and microbial parameters. *Environ Sci Pollut Res* 19: 3400 – 3411

Aranda, Y., Bhatt, P., Ates, N., Engel, B., Simsek, H. (2023) Cyanophage-cyanobacterial interactions for sustainable aquatic environment. *Environmental Research*. 229: 115728

Anantapatula, S., and Wilson A. (2024) Most treatments to control freshwater algal blooms are not effective: Meta-analysis of field experiments. *Water Research*. 243:120342

Backer, L., Manassaram-Baptiste, D., LePrell, R., Bolton, B. (2015) Environmental data from Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007 – 2011. *Toxins* 7: 1048 – 1064

Backovic, D., Tokodi, N., Nikolin, B., Svircez, Z. (2020) Cyanobacteria – insidious foe of the skin? *Journal of Water and Health* 18.3.

Bennell, M. Joyce, A., Gardner, E., Frontenac, K., Majury, A. (2015) An evaluation of Southeastern Ontario recreational water quality. *International Prespectives.* 77:10 26-33

Bertani, I., Steger, C., Obenour, D., Fahnenstiel, G., Bridgeman, T., Johengen, T., Sayers, M., Schuchman, R., Scavia, D. (2017) Tracking cyanobacterial blooms: Do different monitoring approaches tell the same story? *Science of the Total Environment* 575: 294 – 308

Burnford, M., Carey, C., Hamiltion.D., Huisman, J., Paerl H., Wood, S., Wulff, A. (2020) Perspecitve: Advancing the research agenda for improving understanding of cyanobacteria in a future of global change. *Harmful Algae*, 91.

Chapra, S., Boehlert, B., Fant, C. Bierman, V., Henderson, J., Mills, D., Mas, D., Rennels, L., Jantarasami, L., Martinish, J., Strzepek, K., Paerl, H. (2017) Climate change impacts on harmful algal blooms in U.S freshwaters: a screening level assessment. *Environmental Science and Technology*

Chorus, I. and Bartram, J. (1999) Toxic cyanobacteria in water: A guide to public health consequences, monitoring and management. *E & FN Spon.* Suffolk.

Dellinger, J., Dorevitch, S., Faustman, E., Foldy, S., Takaro, T. 2017. Human health effects of cyanobacterial toxins in the great lakes region: A science and monitoring assessment. *International Joint Commission by the Health Professionals Advisory Board*

Drobac, D., Tokodi, N., Simeunovic, J., Baltic, V., Stanic, D., Svircev, Z. (2013) Human exposure to cyanotoxins and their effect on health. *Arh Hig Rada Toksikol* 64: 305 – 316

Funari, E., Manganelli, M., Buratti, F., Testai, E. (2017) Cyanobacteria blooms in water: Italian guidelines to assess and manage the risk associated to bathing and recreational activities. *Science of the Total Environment* 598: 867 – 880

Gaget, V., Almuhtaram, H., Kibuye, F., Hobson, P., Zamyadi, A., Wert, E., Brookes, J. (2022) Benthic Cyanobacteria: A utility-centered field Study. *Harmful Algae*. 133.

Gong, P., Antrim, A., Bickman, S., Cooley, E., Chung, S. (2022) Sandwich hybridization assay for in situ real time cyanobacterial detection and monitoring: A review. *Biosensors*. 12:640

Health Canada (2012) Guidelines for Canadian Recreational Water Quality, Third edition. Water, Air, and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Howard, M., Kudela, R., Hayashi, K., Tatters, A., Caron, D., Theroux, S., Oehrle, S., Roethler, M., Donovan, A., Loftin, K., Laughrey, Z. (2021) Multiple co-occuring and persistently detected cyanotoxins and associated cyanobacteria in adjacent California lakes. *Toxicon*

Huisman, J., Codd, G., Paerl, H., Ibelings, B., Verspagen, J., Visser, P. (2018) Cyanobacterial Blooms. *Nature Reviews: Microbiology*. 16.471.

Kaloudis, T., Hiskia, A., Triantis, T. (2022) Cyanotoxins in bloom: Ever-increasing occurrence and global distribution of freshwater cyanotoxins from planktic and benthic cyanobacteria. *Toxins*. 14:264

Lad, A., Breidenbach, J., Su, R., Murray, J., Kuang, R., Mascarenhas, A., Najjar, J., Patel, S., Hegde, P., Youssef, M., Breuler, J., Kleinhenz, A., Ault, A., Westrick, J., Modyanov, N., Kennedy, D., Haller, S. (2022). As we drink and breathe: Adverse health effects of microcystins and other harmful algal bloom toxins in the liver, gut, lungs, and beyond. *Life*. 12:48

Lee, T., Rollwagen-Bollens, G., Bollens, S., Faber-Hammond, J. (2015) Environmental influence of cyanobacteria abundance and microcystin toxin production in a shallow temperate lake. *Ecotoxicology and Environmental Safety* 114: 318 – 325

Lin, C., Wade, T., Sams, E., Dufour, A., Chapman, A., Hilborn, E. (2016) A prospective study of marine phytoplankton and reported illness among recreational beachgoers in Peurto Rico, 2009. *Environ Health Perspect* 124:477-483

McGregor, G., Stewart, I., Sendall, B., Sadler, R., Reardon, K., Carter, S., Wruck, D., Wickramasinghe, W. (2012) First report of a toxin *Nodularia spumingena* (Nostocales/cyanobacteria) bloom in sub-tropical Australia.I phycological and public health investigations. *Int. J. Environ. Res. Public Health* 9: 2396 - 2411

Metcalf. J., Codd, G. (2020) Co-Occurrence of cyanobacteria and cyanotoxins with other environmental health hazards: Impacts and implications. *Toxins.* 12, 629.

Mishra, S., Stumpf, R., Schaeffer, B., Werdell, J., (2023) Recent changes in cyanobateria algal bloom magnitude in large lakes across the contiguous United States. *Science of the Total Environment*. 897:165253.

Mutoti, M., Edokpayi, J., Mutileni, N., Durowoju, O., Munyai, F. (2023) Cyanotoxins in groundwater; occurrence, potential sources, health impacts, and knowledge gap for public health. *Toxicon.* 226; 107077

Nielsen, M., Jiang, S. (2020) Can cyanotoxins penetrate human skin during water recreation to cause negative health effects? *Harmful Algae*. 98

Osborne, N., Shaw, G., Webb, P. (2006) Health effects of recreational exposure to Moreton Bay, Australia waters during a *Lynbya majuscula* bloom. *Environment International* 33 309 – 314.

Otten, T. and Paerl, H. (2015) Health effects of toxic cyanobacteria in U.S. drinking and recreational waters: Our current understanding and proposed direction. *Current Environmental Health Reports* 2: 75 -84

Pinto, A., Botelho, M., Churro, C., Asselman, J., Pereira, P., Pereira, J. (2023) A review on aquatic toxins – Do we really know it all regarding the environmental risk posed by phytoplankton neurotoxins? *Journal of Environmental Management*. 345; 118769

Plaas, H., Paerl, H. (2021) Toxic cyanobacteria: A growing threat to water and air quality. *Environmental Science and Technology*. 55, 44-64.

Persuad, A., Paterson, A., Dillon, P., Winter, J., Palmer, M., Somers, K. (2015) Forecasting cyanobacterial dominance in Canadian temperate lakes. *Journal of Environmental Management* 151: 343 – 352

Rastogi, R., Madamwar, D., Incharoensakdi, A. (2015) Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Frontiers in Microbiology* 6: 1254

Reif, J., Stockley, N., Harvey, K., McFarland, M.,Gordon, S., Schaefer, A. (2023) Symptom frequency and exposure to a cyanobacteria bloom in Florida. *Harmful Algae*. 129: 102526

Schafer. A., Yrastorza, L., Stockley, N., Harvey, K., Harris, N., Grady, R., Sullivan, J., McFarland, M., Reif, J. (2020) Exposure to microcystin among coastal residents during a cyanobacteria bloom in Florida. *Harmful Algae*. 92

Stewart, I., Webb, P., Schluter, P., Shaw, G. (2006 A) Recreational and occupational field exposure to freshwater cyanobacteria – a review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. *Environmental Health: A Global Access Science Source* 5:6.

Stewart, I., Webb, P., Schluter, J. Fleming, L., Burns, J., Gantar, M., Backer, L., Shaw, G. (2006 B) Epidemiology of recreational exposure to freshwater cyanobacteria – and international prospective cohort study. *BioMed Central Public Health* 6:93.

Sun, Y., Guo, Y., Xu, C., Liu, Y., Zhao, X., Liu, Q., Jeppesen, E., Wang, H., Xie, P. (2023) Will "air eutrophication" increase risk of ecological threat to public health*? Environmental Science and Technology*. 57:10512-10520.

Svircev, Z., Drobac, D., Tokodi, N., Vidovic, M., Simeunovic, J., Milandinov-Mikov, M., Baltic, V. (2013) Cancer in Serbia and possible connection with cyanobacterial blooms. *Journal of Environmental Science and Health,* Part C, 31:181 – 200.

Van de Waal, D., Gsell, A., Harris, T., Paerl, H., de Sederpont Domis, L., Huisman, J. (2024) Hot summers raise public awareness of toxic cyanobacterial blooms. *Water Research*. 249:120817.

Vaughan, L., Zamyadi, A., Ajjampur, S., Almutaram, H., Freguia, S. (2022) A review of microscopic cell imaging and neural network recognition for synergistic cyanobacteria identification and enumeration. *Analytical Sciences* 38:261-279

Vidal, F., Sedan, D., D'Agostino, D., Cavalieri, M., Mullen, E., Parot Varela, M., Flores, C., Caixach, J., Andrinolo, D. (2017) Recreational exposure during algal bloom in Carrasco Beach, Uraguay: A liver failure case report. *Toxins.* 9:267

Volk, A., Lee, J. (2023) Cyanobacterial blooms: A player in freshwater environmental resistome with public health relevance*? Environmental Research*. 216:114612

Wang,Z., Chen, Q., Zhang, J., Xu, H., Miao, L., Zhang, T., Liu, D., Yan, H., Yan, D. (2024) Climate warming promotes collateral antibiotic resistant development in cyanobacteria. *Water Research*. 256:121642

Watson, S., Zastepa, A., Boyer, G., Matthews, E. (2017) Agal bloom response and risk management: on site response tools. *Toxicon.* 129.

Whitman, P., Schaeffer, B., Salls, W., Coffer, M., Mishra, S., Seegers, B., Loftin, K., Stumpf, R., Werdell, J. (2022) A validation of satellite derived cyanobacteria detections with state reported events and recreation advisories across U.S. lakes. *Harmful Algae.* 115:102191

(WHO) World Health Organization (2003) Guidelines for safe recreational water environments. Volume 1: Coastal and fresh waters. Geneva, Switzerland.

Wood, R. (2016) Acute animal and human poisonings from cyanotoxin exposure – A review of the literature. *Environment International* 91:276-282

Chapter 2

2.0 Literature Review Article: An overview of cyanobacteria trends and exposure effects for public health policy

By Kristyn Madrick

Abstract

Objectives

To provide a brief overview of current knowledge about cyanobacteria trends around the world and within Ontario with a focus on the health risks of exposure to cyanobacteria through recreational water use.

Methods

Articles were obtained from a systematic search of the PubMed data base and selected to represent a broad range of aspects about cyanobacteria and human health.

Synthesis

Global trends and climate change are showing increases in the number, severity, and frequency of cyanoblooms with more temperate regions expecting to see large changes in coming years. There is a distinct lack of epidemiological studies on cyanobacterial exposure through recreational water use which can be applied to other regions due to the variability of cyanobloom characteristics across time and space. The effects of cyanobacteria exposure are highly variable and current studies have identified many avenues of future research into possible severe

consequences of cyanobacteria exposure including increased cancer rates and exposure routes that are currently not covered by public health regulation. The existing guidelines from the WHO which are the basis for most national and regional guidelines have been criticised for being too lenient and not covering all possible exposure routes.

Conclusion

There is potential for cyanobacterial exposure to become more common in the future and current public health measures may not be adequate. Additional study is required in a wide number of areas relating to cyanobacteria and human health.

Word Count: 4 481

2.1 Introduction

Cyanobacteria are prevalent in most aquatic environments, and their overgrowth can lead to hazardous toxin levels that risk human health. Climate change may be increasing the frequency of cyanobacterial blooms, raising concerns about exposure through recreational water use. Ontario is home to one of the world's largest freshwater reserves and millions of lakes (Dellinger et al., 2017). Many residents and visitors engage in water activities during the summer, contributing to the regional economy and recreational culture (County of Simcoe, 2014; County of Simcoe Economic Development Office, 2016; District of Muskoka, 2016). Although cyanoblooms have been relatively rare in the area, an increase in their occurrence could pose public health risks if current monitoring and management practices are insufficient (Health Canada, 2012; Dellinger et al., 2017). This literature review aimed to provide a narrative overview of global trends in cyanobacteria prevalence, the health impacts of exposure, and the procedures in Ontario for monitoring recreational waters to mitigate these risks.

2.2 Methods

This research used the PubMed database for article collection. Articles were found using the title search keywords: ‘cyanobacteria’, ‘blue-green algae’, ‘cyanobacteria epidemiology’ and ‘blue-green algae epidemiology’ as these provided broad results for multiple types of studies which focused specifically on cyanobacteria and cyanobacteria related illness. The articles included in this review are some of the most relevant to the search terms and intended to represent an overview of the topic. This narrative review is not exhaustive and was intended to provide an overview to direct further inquiries into this field.

2. Synthesis

2.3 Cyanobacteria Characteristics

Cyanobacteria, commonly referred to as blue-green algae, are categorized as Cyanophyceae; a diverse group of prokaryotic organisms that first appeared 2.3 billion years ago (Stewart et al., 2006a; Svircev et al., 2013). Cyanobacteria are notable for the number and variety of compounds that they produce, including multiple toxins which are unique to cyanobacteria (Stewart et al., 2006a). While cyanobacteria occur normally in nearly all water bodies, overgrowth of cyanobacterial colonies can cause major environmental problems. Cyanobacterial overgrowth is called a bloom, cyanobloom, or harmful algal bloom (HAB) (Almeida et al., 2012; Backer et al., 2015; McGregor et al., 2012). A bloom is usually characterized by a high cell density exceeding 20,000 cells per millilitre of water though this definition is not universally accepted and Aguilera and colleagues (2023) identified thirteen different thresholds for cell abundance globally (Graham et al., 2012; Aguilera et al., 2023). Blooms are typically identified visually as they create thick surface scums or impart a bright turquoise to green hue to the water, resembling paint (Health Canada, 2012).

2.4 Causes of Cyanoblooms

Interacting factors of eutrophication, water temperature, and water column stability, contribute to the development of bloom conditions (Huber et al., 2012). Phosphorus and nitrogen typically serve as limiting factors for cyanobacterial growth, but eutrophication, nutrient overloading from human activities, can introduce excess nutrients to support exponential growth (Huber et al., 2012; Almeida et al., 2012). Cyanobacteria can survive in lower light and oxygen conditions than most other algae and aquatic plants (Almeida et al., 2012; Health Canada, 2012). Dense surface blooms restrict oxygen exchange between the air and water, leading to hypoxic or even anoxic conditions (Lee et al., 2015). Low oxygen levels can devastate aquatic plants and organisms (Lee et al., 2015). Ultimately, the escalating growth of cyanobacteria worsen the conditions that triggered their proliferation, creating a feedback loop that further increases algal populations (Almeida et al., 2012). Most cyanobacteria species achieve their maximum growth rate at temperatures above 25°C, making blooms in Canada most prevalent in late summer and early fall (Health Canada, 2012). In Ontario, the bloom season occurs from June through October (Wynn and Stumpf, 2015), although some lakes may experience blooms beyond this timeframe.

2.5 Global Warming and Cyanoblooms

Cyanobacterial blooms are more frequent and severe in warmer conditions, indicating that climate change may lead to a rise in the occurrence and intensity of harmful bloom events (Huber et al., 2012; Stewart et al., 2006a; McGregor et al., 2012; Persuad et al., 2015). Over the past two centuries, there has been a global increase in toxic cyanobacterial blooms (Bertani et al., 2017). An analysis of sediment cores from 100 lakes in North America revealed that occurrences of cyanobacterial blooms have risen significantly, outpacing the growth of other phytoplankton since the industrial revolution (Huisman et al., 2018). Sediment studies from the Baltic Sea indicate that while cyanoblooms have occurred for thousands of years, their frequency has notably increased since the 1960s (Huisman et al., 2018). An extensive bloom was first reported in the Mediterranean Sea in 2010, marking an unprecedented northward expansion of cyanobacterial blooms (Huisman et al., 2018). Lake Erie experienced significant blooms during the 1960s and early 1970s, but reductions in phosphorus loading led to a decline in blooms during the 1980s; however, there was a resurgence in the 1990s (Huisman et al., 2018). In 2011, a combination of high nutrient levels and a prolonged warm summer resulted in a record-setting bloom that spanned 5 000 km of Lake Erie (Huisman et al., 2018).

Warmer conditions and the increased frequency of blooms may favour the proliferation of more toxigenic species and strains within those species (Qin et al., 2015; Svircev et al., 2012; Rastogi et al., 2015). On average, about 60% of blooms possess toxin-producing capabilities, and certain species can have both toxic and non-toxic cells, making it difficult to identify toxic algae based on their morphology (Lee et al., 2015; Health Canada, 2012).

Range expansion is a significant concern, as more toxic strains from tropical or subtropical regions, may move into temperate areas (McGregor et al., 2012). This indicates that cyanobacteria could pose a greater health risk in the future, as blooms may appear in water bodies that have not previously experienced them (Backer et al., 2015; Greenfield et al., 2014; Qin et al., 2015; Rastogi et al., 2015).

Climate change increases the frequency of extreme precipitation events which can increase fertilizer and surface runoff, and sewage treatment plant bypasses (Chapra, et al., 2017). Increased flows add more nutrients to overloaded lakes (Chapra, et al., 2017). Climate change may also increase drought periods, causing water in lakes and reservoirs to become warmer and stagnant: conditions that are favourable to cyanobacterial blooms (Chapra et al., 2017).

Chapra and colleagues (2017) created a screening analysis of the contiguous United States' water bodies that included projections of climate change, greenhouse gas emissions, global atmospheric circulation, and cyanobacterial growth scenarios to create projections of cyanobacterial loads in the future. They estimated that on average, cyanobloom occurrences would increase from 7 days per year per waterbody to 16 to 23 days per year by 2050, and 18 to 39 days per year by 2090 (Chapra et al., 2017).

However; research by Mishra and colleagues (2023) did not find the anticipated overall increase in algal blooms in a large sample of lakes across the contiguous United States from 2016 to 2020, compared to data from 2008 to 2011 (Mishra et al., 2023). In most regions analyzed, cyanobloom occurrences were lower between 2016 and 2020 than in the earlier time period, although regions experiencing the most significant temperature increases did see some rise in cyanobloom frequency (Mishra et al., 2023). The research indicated that the anticipated increase in bloom magnitude may occur over a longer timescale than previously thought (Mishra et al., 2023). The authors concluded that the interaction of temperature, precipitation, land use and agricultural practices requires a more nuanced ecosystem-scale model to accurately assess the impact of rising temperatures on cyanobloom magnitude (Mishra et al., 2023).

2.6 Cyanobacterial Toxins

Over 46 species of cyanobacteria are capable of producing toxins (Health Canada, 2012). The cyanotoxins can be classified by compound type: cyclic peptides (i.e., microcystins, nodularins), alkaloids (i.e., anatoxin – a, and a(s), saxitoxins, cylindrospermopsin, aplysiatoxin, lyngbiatoxin – a) and lipopolysaccharides (Rastogi et al., 2015). Cyanotoxins may also be classified into functional groups based on their action in the body: hepatotoxins, neurotoxins, cytotoxins, dermatotoxins, and irritant toxins (Rastogi et al., 2015; Drobac et al., 2013; Stewart et al., 2006 a; Otten and Paerl, 2015). Cyanotoxins can affect the cellular system through: disorganization of the cytoskeleton, cell proliferation, genome damage, inhibition of enzyme activity, imprecise mitotic cell divisions, loss of membrane integrity, oxidative stress and lipid peroxidation

(Rastogi et al., 2015). Testing for toxicity is time consuming and expensive, thus for practicality within public health, all blooms are assumed to be toxic by default (Health Canada, 2012).

2.7 Exposure Routes

Cyanotoxin poisoning can occur through dermal, inhalational, and ingestion routes. Cyanobacterial contamination of drinking water is rare in developed countries; however, when it occurs, it can cause large scale exposures (WHO, 2003; Health Canada, 2012; Qin et al., 2015). From 1930 to 1931 approximately 9 000 people in the City of Charleston, Ohio were exposed to cyanotoxins through drinking water drawn from a bloom in the Ohio River (Wood, 2016). During 2014 nearly 500 000 residents of Toledo, Ohio lost access to drinking water when testing revealed cyanotoxins in treated water (Chapra et al., 2017).

The intake pipes for drinking water treatment in developed countries are typically far offshore and below the thermocline cyanoblooms inhabit (Svircev et al., 2013; Rastogi et al., 2015; Chapra et al., 2017). The typical filtration processes for drinking water can remove the cyanobacterial cells but not the toxins (Rastogi et al., 2015; Svircev et al., 2013). Reverse osmosis can reduce toxin levels in treated water but it may only be 60% effective and the cost of such systems is prohibitive (Chapra et al., 2017).

Recent research indicates that groundwater can become contaminated with cyanotoxins when surface water containing toxins recharges groundwater as soil cannot filter or degrade cyanotoxins (Mutoti et al., 2023).Groundwater accounts for about 30% of all freshwater and is commonly extracted for drinking water without treatment (Mutoti et al., 2023). Research on cyanotoxin levels in groundwater has been limited, but some tests have indicated concentrations exceeding safe consumption guidelines, suggesting a need for further investigation (Mutoti et al., 2023).

Recent research has indicated that inhalational exposure to cyanotoxins may pose a risk to human health (Sun et al., 2023). Algae measuring between 0.5 and 5 micrometers can be released from surface water, with about 10% remaining airborne for up to four days and traveling distances of up to 11 000 km and aerosols containing toxins can travel over 30 km from contaminated water sources (Sun et al., 2023). Humans, on average, inhale more than 11 000 litres of air daily (Lad et al., 2022). Algal cells and toxins can settle in the nostrils and lungs which may lead to skin irritation and respiratory issues (Sun et al., 2023). Notably, the median lethal dose for inhaled cyanotoxins is lower than for oral ingestion (Sun et al., 2023). Study by Reif and colleagues in 2018 found that even participants who did not directly interact with affected waterbodies showed increased respiratory illnesses and had detectable cyanotoxins in nasal swabs (Reif et al., 2023).

In developed countries, populations are primarily exposed to cyanobacteria through water-based recreational activities. Wood (2016) estimated that about half of all human exposures to cyanotoxins occur during recreational water use. Chapra and colleagues (2017) reported that nearly half of all recreational waterborne disease outbreaks in the U.S. during 2009 and 2010 were linked to cyanobacteria.

The World Health Organization (WHO) established a risk assessment categorization system for cyanotoxin exposure in recreational water in 2003; however, these guidelines have faced criticism for lacking standardized testing methods and utilizing research that was outdated and not representative of the most likely exposure cases (Chorus and Bartram, 1999; Funari et al., 2017).

2.8 Cyanotoxin Poisoning

Cyanobacterial toxin poisoning (CTP) can lead to a wide range of symptoms based on the type of toxin, the route and amount of exposure, and individual sensitivity (Rastogi et al., 2015; Stewart et al., 2006a; Osborne et al., 2006). For microcystin, one of the most prevalent cyanotoxins, the lethal dose for 50% of exposed humans (LD50) is 50 micrograms per kilogram (Wood, 2016). Cyanotoxins can affect the body within minutes to hours after exposure (Wood, 2017). The WHO has determined that there is a high probability of adverse health effects from contact with water containing cell concentrations over 100 000 cells per millilitre (Backovic et al., 2020). Acute exposures can cause: headache, fever, sore throat, cough, myalgia, pneumonia, abdominal pain, vomiting, diarrhoea, dermatitis, blistering of the mouth, weakness, and muscle tremors (Stewart et al., 2006a; Osborne et al., 2006). Serious acute and long term exposures may result in: kidney impairment, liver damage or cirrhosis, septic shock, and impairment of immune function in animal models (Rastogi et al., 2015). Lad and colleagues (2022) noted that there is significant need to investigate how pre-existing health conditions may affect susceptibility to cyanotoxin poisoning. Evidence suggests that chronic exposures to cyanotoxins, even at levels well below guidelines, can exacerbate hepatic injury in individuals with non-alcoholic fatty liver disease (NAFLD) (Lad et al., 2022). NAFLD affects between 75% and 92% of obese individuals in North America, and while some studies suggest that cyanotoxin exposure might contribute to the disease's development, there is limited research on its effects in those who already have the condition (Lad et al., 2022). Additionally, Lad and colleagues (2022) noted correlations between cyanotoxin exposure and impaired kidney function, gastrointestinal and colorectal carcinoma, and gastroenteritis; though it remains unclear whether cyanotoxins are causative factors or exacerbate pre-existing conditions.

Diagnosing cyanobacterial toxin poisoning is difficult due to the range of symptoms, which can overlap with other afflictions (Health Canada, 2012; Graham et al., 2008). Additionally, cyanobacterial blooms often coincide with elevated levels of fecal coliforms, which may cause similar symptoms and also result from recreational water use (Health Canada, 2012; Graham et al., 2008). Cyanobacteria may serve as a reservoir for antibiotic-resistant genes in the environment and facilitate gene transmission to other bacteria, but further research is necessary (Metcalf and Codd, 2020; Volk and Lee, 2023; Wang et al., 2024). It is also possible for the extracellular materials of cyanobacterial blooms to harbour pathogenic bacteria, such as cholera (Metcalf and Codd, 2020).

The reaction to cyanobacterial antigens appears to vary among individuals, which suggests that susceptibility may play a role (Backovic et al., 2020). Backovic and colleagues (2020) found that around 20% of healthy individuals reacted to cyanobacteria extracts; however, the sample sizes were quite small. In tests using a skin prick method, 86% of participants exhibited adverse reactions, which may indicate that broken skin is more vulnerable to cyanobacterial toxins (Backovic et al., 2020). There is also some evidence that exposure to these toxins may both initiate and accelerate the growth of skin tumours (Backovic et al., 2020).

There is no antidote for cyanotoxin poisoning; treatment is solely symptomatic (Health Canada, 2012). While there have been numerous reports of animal fatalities due to cyanotoxins, human fatalities are rare (Stewart et al., 2006a; Chorus and Bartram, 1999; Otten and Paerl, 2015). Most cases of acute cyanobacterial exposure are not severe; Osborne and colleagues (2007) estimated that severe reactions occur in only 1.3% to 2.7% of cases involving benthic cyanobacteria, which pose a lower health risk compared to scum-forming species (Graham et al., 2008). Between 2009 and 2010, the U.S. Centers for Disease Control and Prevention (CDC) reported 11 confirmed illness outbreaks attributed to cyanotoxins (Funari et al., 2017).

2.9 Epidemiological Studies of Cyanotoxin Exposure

There have been few epidemiological studies regarding the frequency and severity of cyanobacterial exposure associated illnesses. The studies that have been conducted are difficult to generalize due to the large number of cyanobacteria species, the range of toxins that are produced, the diversity of reactions between individuals, and the often small sample sizes (Stewart et al., 2006a).

Pilotto and colleagues conducted the earliest known epidemiological study of cyanobacteria in 1995 (Pilotto et al., 1997). The study consisted of a prospective cohort of 852 participants who were approached at beaches in South Australia. Participants exposed to 5 000 cells per millilitre or more for one hour were significantly more likely (OR=1.87; 95% CI = 0.68 – 1.54) to report symptoms associated with cyanotoxin exposure seven days after exposure, compared to unexposed individuals. The prospective cohort design was useful in approximating the prevalence of symptoms after exposure, which could be attributed to cyanobacterial exposure. However; the study had a small control sample and variation in the exposure times and concentrations along with potential confounding factors made it difficult to attribute symptoms to cyanobacteria with any surety.

Stewart and colleagues conducted a prospective cohort study involving 1 331 respondents from 1999 to 2002 in southeast Queensland, Australia and central Florida in the United States (Stewart et al., 2006a). Participants were recruited at beaches and completed a survey before leaving. Three days after exposure, they were contacted by phone for interviews about both chronic and recent acute illnesses. Water samples were taken on all study days to measure cyanobacterial cell surface area and the presence of fecal coliforms on select days. The study found that individuals exposed to higher levels of cyanobacteria were more likely to report symptoms associated with cyanobacterial exposure, with an odds ratio of 1.7 (95% CI 1.0–2.9). However, the researchers noted that cyanobacterial cell concentrations remained low in the water throughout the study, and the inconsistent sampling of fecal coliforms could have confounded the results.

Osborne and colleagues (2007) conducted a mail survey involving 5 000 residents living in an area of Australia experiencing annual marine blooms. They had a response rate of 27%, with 78% of respondents having engaged in recreational activities in the affected waterbody. Among those who participated in water-based activities, 34% reported experiencing at least one symptom afterward, with 0.6% noting symptoms associated with the cyanobacterial species in bloom. Individuals aware of cyanobacteria were less likely to report symptoms. However, recall bias may have influenced the results, as participants were asked to reflect on their experiences over the previous seven months. Selection bias could have affected the results, as those who experienced symptoms may have been more inclined to respond to the survey.

Svircev and colleagues conducted a longitudinal observational study of a population in Serbia chronically exposed to cyanotoxins through drinking water (Svircev et al., 2013). They analyzed existing reports on the incidence of various illnesses and compared the results from the exposed population to an unexposed population. The study found a significant increase in the occurrence of primary liver cancer among the exposed populations, despite no corresponding increase in common risk factors for the disease, such as cirrhosis and hepatitis. The mortality rate from primary liver cancer in the exposed population was 11.6%, compared to 7.6% in the unexposed population. Because the study was observational, relying on existing healthcare data, it could not definitively establish whether cyanotoxin exposure was the cause of the increased prevalence.

Lin and colleagues conducted a prospective cohort study of 15 726 participants in Puerto Rico in 2009 (Lin et al., 2016). Participants with higher levels of exposure (i.e. higher cell density in the water during engagement, longer duration of activity, high risk behaviours including ingestion of water) were more likely to report symptoms of cyanotoxin poisoning than individuals with lower exposure. The researchers had 75% response rate which reduces the likelihood of selection bias.

Reif and colleagues (2023) conducted a prospective study of 125 participants in August and September 2018 near Lake Okeechobee and the St. Lucie River, experiencing cyanoblooms. Participants completed a questionnaire regarding their proximity to waterways, details of occupational and recreational exposure, chronic illness assessments, and any symptoms that occurred within 10 days of exposure. Surface water samples were collected from the waterways adjacent to the recruitment areas. The study found that 93 participants (74.4%) reported respiratory symptoms, 62 (49.6%) reported ocular symptoms, 44 (35.2%) reported gastrointestinal symptoms, 54 (43%) reported headaches, and 13 (10%) reported skin rashes (Reif et al., 2023). Participants who had history of respiratory conditions, including asthma and allergies, were twice as likely to report respiratory symptoms (Reif et al., 2023). The researchers noted that elevated frequency of health effects was not limited to those who interacted directly with affected water bodies but also those who lived near the water (Reif et al., 2023). The researchers concluded that aerosolized toxins may pose a significant threat, particularly to those with pre-existing respiratory conditions (Reif et al., 2023).

2.10 Cyanotoxin Exposure Case Studies

In 1979, an outbreak of hepatoenteritis in Palm Island, Australia, hospitalized 140 children and 10 adults for vomiting, headaches, diarrhoea, and dehydration, with some individuals suffering acute kidney and liver damage (Lad et al., 2022). This outbreak was linked to the Solomon Dam reservoir, where a cyanobacterial bloom had been treated with copper sulfate, causing the release of the cylindrospermopsin into the water supply (Lad et al., 2022).

In Caruaru, Brazil, in 1996, 131 patients undergoing hemodialysis were exposed to microcystins and cylindrospermopsin through dialysate that had been prepared with contaminated water. Of these, 116 showed symptoms consistent with cyanotoxin exposure, 100 developed acute liver failure, and 76 died (Lad et al., 2022; Mishra et al., 2023).

Geh and colleagues (2016) reported on the case of an 11-year-old girl who was exposed to cyanobacteria while playing in Lake Ontario, Canada. After playing with cyanobacterial scum and applying sunscreen, she developed a rash and blisters during the night, and briefly lost consciousness upon waking the next morning. At hospital, she was treated with diphenhydramine every 4 to 6 hours, but the rash seemed to worsen as the medication wore off. On the third day after exposure, the rash intensified, and she was prescribed oral corticosteroids. Eight days after exposure, an allergist prescribed an epinephrine auto-injector and topical corticosteroids. The symptoms resolved after ten days. Allergy testing confirmed that she had developed an allergy to cyanobacteria.

Vidal and colleagues (2017) reported the case of a 20-month-old child exposed to cyanotoxins at a beach in Uruguay in 2015. The child required hospitalization due to liver failure and ultimately needed a liver transplant. Analysis confirmed that the liver damage was caused by cyanotoxins (Vidal et al., 2017).

2.11 Measures for Combating Cyanotoxins

Controlling cyanoblooms is challenging, as blooms exacerbate the conditions that create them resulting in a feedback loop (Almeida et al., 2012). Long-term solutions involve nutrient management to reduce nitrogen and phosphorus runoff, requiring coordinated efforts from landowners, businesses, and municipalities (Aranda et al., 2023; Anantapatula and Wilson, 2024). While various treatments exist for ongoing blooms, meta-analysis by Anantapatula and Wilson found that most *in situ* treatments did not significantly improve water quality. Only four of 18 chemical treatments showed notable effects, and bacterial, physical, or plant-based treatments yielded no improvements (Anantapatula and Wilson, 2024). Manual netting to remove surface scum is the most effective method, resulting in lower toxin release compared to algaecides with the added benefit removing pollutants and heavy metals which cyanobacteria absorb (Su et al., 2012; Qin et al., 2015). However, this method cannot eliminate extracellular toxins, which can remain elevated for over nine days post-bloom (Wood, 2017; Greenfield et al., 2014). Currently, no established treatments effectively remove toxins from surface waters (Mrdjen and Lee, 2018).

2.13 Guidelines for Cyanoblooms

The primary method for detecting cyanobacterial blooms is visual inspection for large floating scums (Health Canada, 2012; Persuad, 2015; Graham et al., 2008). The Guidelines for Canadian Recreational Water Quality include the Recreational Swimming Area Environmental Checklist, which mandates visual inspections of public beach areas, however, blooms may not always be easily visible, and toxin concentrations in the water can fluctuate rapidly due to wind and water movement (Health Canada, 2012; Graham et al., 2008; Greenfield et al., 2014).

Funari and colleagues (2017) indicate that most global guidelines on cyanotoxins are based on the WHO guidelines published in 2003. Research informing these guidelines focused on a single cyanotoxin, neglecting the toxicity and concentration variations exhibited by different cyanobacteria. Additionally, the guidelines were developed with the assumption of exposure for a 60 kg adult, meaning that children, who are more likely to ingest larger amounts of water compared to adults, could face higher toxin concentrations per kilogram (Funari et al., 2017). Additionally, basing guidelines solely on cell volume does not account for the varied amounts and types of toxins cyanobacterial cells can produce, or the concentration of extracellular toxins in the water. Funari and colleagues advocate for revisions to the WHO guidelines to incorporate recent advancements in understanding cyanobacteria (Funari et al., 2017)

Nielsen and Jiang (2020) noted that current guidelines for cyanobacteria in recreational water focus solely on ingestion, overlooking common dermatological issues associated with exposure. The physiochemical properties of cyanotoxins suggest they may penetrate human skin. Research indicates that 5 to 15% of individuals experience allergic reactions or skin irritation from cyanobacterial exposure (Nielsen and Jiang, 2020; Pilotto et al., 2004; Stewart et al., 2006). The authors noted that the inconsistencies between reported illnesses and dermal study findings, suggest that cyanotoxins may penetrate the skin barrier and enter the bloodstream, (Nielsen and Jiang, 2020).

Additionally, the WHO guidelines do not address aerosolized exposure to cyanobacteria. Plaas and Paerl (2021) noted that cyanobacterial cells and toxins can be found in air samples near waterbodies experiencing blooms, but they noted that further research to assess the potential effects of these aerosolized toxins on humans is necessary. Schaefer and colleagues (2020) studied individuals who worked or partook in recreational activity on waters impacted by a cyanobacterial bloom, finding that 95% had detectable levels of microcystin in their nasal mucosa, with the highest concentrations during the bloom's peak. Although these nasal concentrations were below the current acceptable limits for oral ingestion, no established limits exist for inhalational exposure (Schaefer et al., 2020).

2.14 Conclusion

There are significant indications that the prevalence of cyanoblooms have increased since the industrial revolution and may increase even more rapidly due to the effects of climate change. Climatic changes are expected to cause cyanoblooms to become more frequent, more severe, and more toxigenic, and they will expand into regions that have not experienced blooms before. Canada must prepare for these changes by examining and updating the current policies and procedures in place for cyanobacteria monitoring and response. The current Health Canada guidelines have been criticized for basing protocols on out of date and inadequate research which leaves risk for illness to occur in vulnerable individuals even if guidelines are followed correctly. The health effects of cyanobacterial exposures both acute and long term are still not fully known but given the current indications that cyanobacterial exposure may play a role in the initiation of serious long term illness it is essential that more research is conducted. Ontario, particularly with its large number of highly utilized waterbodies, could see public health challenges should cyanoblooms become more common under guidelines that are not as effective as may be required.

2.15 References

Almeida, C., Gonzalez, S., Mallea, M., Gonzalez, P. (2012) A recreational water quality index using chemical, physical, and microbial parameters. *Environ Sci Pollut Res* 19: 3400 – 3411

Backer, L., Manassaram-Baptiste, D., LePrell, R., Bolton, B. (2015) Environmental data from Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007 – 2011. *Toxins* 7: 1048 – 1064

Backovic, D., Tokodi, N., Nikolin, B., Svircez, Z. (2020) Cyanobacteria – insidious foe of the skin? *Journal of Water and Health* 18.3.

Bennell, M., Joyce, A., Gardner, E., Frontenac, K., Majury, A. (2015) An evaluation of Southeastern Ontario recreational water quality. *International Prespectives.* 77:10 26-33

Bertani, I., Steger, C., Obenour, D., Fahnenstiel, G., Bridgeman, T., Johengen, T., Sayers, M., Schuchman, R., Scavia, D. (2017) Tracking cyanobacterial blooms: Do different monitoring approaches tell the same story? *Science of the Total Environment* 575: 294 – 308

Burnford, M., Carey, C., Hamiltion.D., Huisman, J., Paerl H., Wood, S., Wulff, A. (2020) Perspecitve: Advancing the research agenda for improving understanding of cyanobacteria in a future of global change. *Harmful Algae,* 91.

Calado, S., Wojciechowski, J., Santos, G., Magalhes, V., Padial, A., Cestari, M., Assis, H. (2017) Neurotoxins in a water supply reservoir: an alert to environmental and human health. *Toxicon* 126: 12-22

Chapra, S., Boehlert, B., Fant, C. Bierman, V., Henderson, J., Mills, D., Mas, D., Rennels, L., Jantarasami, L., Martinish, J., Strzepek, K., Paerl, H. (2017) Climate change impacts on harmful algal blooms in U.S freshwaters: a screening level assessment. *Environmental Science and Technology*

Chorus, I. and Bartram, J. (1999) Toxic cyanobacteria in water: A guide to public health consequences, monitoring and management. *E & FN Spon.* Suffolk.

Dellinger, J., Dorevitch, S., Faustman, E., Foldy, S., Takaro, T. 2017. Human health effects of cyanobacterial toxins in the great lakes region: A science and monitoring assessment. *International Joint Commision by the Health Professionals Advisory Board*

Drobac, D., Tokodi, N., Simeunovic, J., Baltic, V., Stanic, D., Svircev, Z. (2013) Human exposure to cyanotoxins and their effect on health. *Arh Hig Rada Toksikol* 64: 305 – 316

Funari, E., Manganelli, M., Buratti, F., Testai, E. (2017) Cyanobacteria blooms in water: Italian guidelines to assess and manage the risk associated to bathing and recreational activities. *Science of the Total Environment* 598: 867 – 880

Gandola, E., Antonioli, M., Traficante, A., Franceschini, S., Scardi, M., Congestri, R. (2016) ACQUA: Automated cyanobacterial quantification algorithm for toxin filamentous genera using spline curves, pattern recognition, and machine learning. *Journal of Microbiological Methods* 124:48-56.

Gaget, V., Almuhtaram, H., Kibuye, F., Hobson, P., Zamyadi, A., Wert, E., Brookes, J. (2022) Benthic Cyanobacteria: A utility-centered field Study. Harmful Algae. 133.

Geh, E., de la Cruz, A., Ghosh, D., Stelma, G., Bernstein, J. (2016) Sensitization of a child to cyanobacteria after recreational swimming in a lake. *J Allergy Clin Immunol* 137(6) 1902 – 1904.

Greenfield, D., Duquette, A., Goodson, A., Keppler, C., Williams, S., Brock, A., Stackley, K., White, D., Wilde, S. (2014) The effects of three chemical algaecides on cell numbers and toxin content of the cyanobacteria *Microcystis aeruginosa* and *Anabaenopsis sp*. *Environmental Management* 54: 1110 – 1120

Harris, P., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., Conde, J. (2009) Research electronic data capture (REDCap) – A metadata-driven methodology and workflow process for providing translational research informatics support, *J Biomed Inform*. Apr;42(2):377-81

Health Canada (2012) Guidelines for Canadian Recreational Water Quality, Third edition. Water, Air, and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Howard, M., Kudela, R., Hayashi, K., Tatters, A., Caron, D., Theroux, S., Oehrle, S., Roethler, M., Donovan, A., Loftin, K., Laughrey, Z. (2021) Multiple co-occuring and persistently detected cyanotoxins and associated cyanobacteria in adjacent California lakes. *Toxicon*

Huber, V., Wagner, C., Gerten, D., Adrian, R. (2012) To bloom or not to bloom: contrasting responses of cyanobacteria to recent heat waves explained my critical thresholds of abiotic drivers. *Oecologia* 169: 245 - 256

Huisman, J., Codd, G., Paerl, H., Ibelings, B., Verspagen, J., Visser, P. (2018) Cyanobacterial Blooms. Nature Reviews: *Microbiology*. 16.471.

Hunter, P., Hanley, N., Czajkowski, M., Mearns, K., Tyler, A., Carvalho, L., Codd, G. (2012) The effect of risk perception on public preferences and willingness to pay for reductions in the health risks posed by toxic cyanobacterial blooms. *Science of the Total Environment* 426: 32 - 44

Lake Simcoe Region Conservation Authority (2016) Lake Simcoe watershed. https://www.lsrca.on.ca/our-watershed Newmarket, Ontario

Lee, T., Rollwagen-Bollens, G., Bollens, S., Faber-Hammond, J. (2015) Environmental influence of cyanobacteria abundance and microcystin toxin production in a shallow temperate lake. *Ecotoxicology and Environmental Safety* 114: 318 – 325

Levesque, B., Gervais, M., Chevalier, P., Gauvin, D., Anassour-Laouan-Sidi, E., Gingras, S., Fortin, N., Brisson, G., Greer, C., Bird, D. (2017) Exposure to cyanobacteria: Acute health effects associated with endotoxins. *Public Health* 134:98-101

Lin, C., Wade, T., Sams, E., Dufour, A., Chapman, A., Hilborn, E. (2016) A prospective study of marine phytoplankton and reported illness among recreational beachgoers in Peurto Rico, 2009. *Environ Health Perspect* 124:477-483

McGregor, G., Stewart, I., Sendall, B., Sadler, R., Reardon, K., Carter, S., Wruck, D., Wickramasinghe, W. (2012) First report of a toxin *Nodularia spumingena* (Nostocales/cyanobacteria) bloom in sub-tropical Australia.I phycological and public health investigations. *Int. J. Environ. Res. Public Health* 9: 2396 - 2411

Metcalf, J., Codd, G. (2020) Co-Occurrence of cyanobacteria and cyanotoxins with other environmental health hazards: Impacts and implications. *Toxins*. 12, 629.

Mrdjen, I., Lee, J. (2018) Simple and practical on-site treatment of high microcystin levels in water using polypropylene plastic. *Journal of Environmental Science and Health, Part A*. 53(11):1000-1005

Nielsen, M., Jiang, S. (2020) Can cyanotoxins penetrate human skin during water recreation to cause negative health effects? *Harmful Algae*. 98

Osborne, N., Shaw, G., Webb, P. (2006) Health effects of recreational exposure to Moreton Bay, Australia waters during a *Lynbya majuscula* bloom. *Environment International* 33 309 – 314.

Otten, T., Paerl, H. (2015) Health effects of toxic cyanobacteria in U.S. drinking and recreational waters: Our current understanding and proposed direction. *Current Environmental Health Reports* 2: 75 -84

Papadimitriou, T., Kormas, K., Dionysiou, D., Laspidou, C. (2016) Using H2O2 treatments for the degradation of cyanobacteria and microcystins in a shallow hypertrophic reservoir. *Environ Sci Pollut Res* 23:21523-21535

Plaas, H., Paerl, H. (2021) Toxic cyanobacteria: A growing threat to water and air quality. *Environmental Science and Technology*. 55, 44-64.

Persuad, A., Paterson, A., Dillon, P., Winter, J., Palmer, M., Somers, K. (2015) Forecasting cyanobacterial dominance in Canadian temperate lakes. *Journal of Environmental Management* 151: 343 – 352

Pilotto, L., Douglas, R., Burch, M., Cameron, S., Beers, M., Rouch, G., Robinson, P., Kirk, M., Cowie, C., Hardiman, S., Moore, C., Attewell, R. (1997) Health effects of exposure to cyanobacteria (blue-green algae) during recreational water-related activities. *Australian and New Zealand Journal of Public Health* 21: (6) 562 – 566

Pitois, F., Vezie, C., Thoraval, I., Baures, E. (2016) Improving microcystin monitoring relevance in recreative waters: A regional case study (Brittany, Western France, Europe). *International Journal of Hygiene and Environmental Health* 219:288-293

Qin, B., Li, W., Zhu, G., Zhang, Y., Wu, T., Gao, G. (2015) Cyanobacterial bloom management through integrated monitoring and forecasting in large shallow eutrophic Lake Taihu (China). *Journal of Hazardous Materials* 287: 356 – 363

Rastogi, R., Madamwar, D., Incharoensakdi, A. (2015) Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Frontiers in Microbiology* 6: 1254

Schafer, A., Yrastorza, L., Stockley, N., Harvey, K., Harris, N., Grady, R., Sullivan, J., McFarland, M., Reif, J. (2020) Exposure to microcystin among coastal residents during a cyanobacteria bloom in Florida. *Harmful Algae*. 92

Stewart, I., Webb, P., Schluter, P., Shaw, G. (2006 A) Recreational and occupational field exposure to freshwater cyanobacteria – a review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. *Environmental Health: A Global Access Science Source* 5:6.

Stewart, I., Webb, P., Schluter, J., Fleming, L., Burns, J., Gantar, M., Backer, L., Shaw, G. (2006 B) Epidemiology of recreational exposure to freshwater cyanobacteria – and international prospective cohort study. *BioMed Central Public Health* 6:93.

Su, Y., Liu, H., Yang., J. (2012) Metals and metalloids in the water-bloom-forming cyanobacteria and ambient water from Nanquan Coast of Taihu Lake, China. *Bull Environ Contam Toxicol* 89: 439 - 443

Svircev, Z., Drobac, D., Tokodi, N., Vidovic, M., Simeunovic, J., Milandinov-Mikov, M., Baltic, V. (2013) Cancer in Serbia and possible connection with cyanobacterial blooms. *Journal of Environmental Science and Health*, Part C, 31:181 – 200.

Watson, S., Zastepa, A., Boyer, G., Matthews, E. (2017) Agal bloom response and risk management: on site response tools. Toxicon. 129.

(WHO) World Health Organization (2003) Guidelines for safe recreational water environments. Volume 1: Coastal and fresh waters. Geneva, Switzerland.

Wolf, D., Georgic, W., Klaiber, H. (2017) Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. *Journal of Environmental Management* 199:148 – 157

Wood, R., (2016) Acute animal and human poisonings from cyanotoxin exposure – A review of the literature. *Environment International* 91:276-282

Wynn, T., Stumpf, P. (2015) Spatial and temporal patterns in the seasonal distribution of toxic cyanobacteria in Western Lake Erie from 2002 – 2014. *Toxins* 7: 1649 – 1663.

Chapter 3

3.0 Mixed Methods Study Article:

Public knowledge, attitudes, and awareness of cyanobacterial health effects in recreational waters of Central Ontario, Canada

By

Kristyn Madrick

Abstract

Objectives

This convergent parallel research assessed information about cyanobacteria exposure presented via news media in Simcoe County and Muskoka District in Ontario, Canada, as well as knowledge and attitudes about cyanobacteria.

Methods

100 news media articles published between January 2013 and May 2019 about cyanoblooms within the region were evaluated for clarity, quality, and utility of information on the health effects of cyanoblooms. A survey of 110 adults from September 2018 to March 2019 gathered information on participants' knowledge of cyanobacteria exposure and health effects, participants' attitudes toward recreational water advisories, and any illness following recreational water activities.

Results

News media articles ranged widely in quality; 33% of articles described how to identify a cyanobloom and 49% described how to avoid contact. Health unit press release articles were consistently of higher quality. The survey revealed that news media was the primary source of information for 71.8% of respondents. Participants rated their concern about cyanobacteria at an average of 71.7 out of 100. Eight participants (8.3%) reported illness after recreational activities in Simcoe/Muskoka waterbodies, six of whom sought medical care. 36.7% of participants could not identify symptoms of cyanotoxin exposure and 30% were unaware of the signs of a cyanobloom. Those who did identify cyanobloom signs rated their confidence at 21.0 out of 100.

Conclusion

Current practices may not be effective in preventing cyanobacteria exposures as people do not have confidence in their ability to recognize the risks. Updating press release templates could improve the information presented in news media.

Word Count: 5 000

3.1 Objectives

Toxin producing cyanobacteria are found in most aquatic environments and large populations of organisms can create dangerous levels of toxins that can cause illnesses to exposed humans (Drobac et al., 2013; Bennell et al., 2015). Cyanobacterial blooms are becoming more common worldwide and may be increasing in frequency, intensity and distribution due to climate change (Qin et al., 2015). Cyanoblooms can potentially cause adverse health events in persons exposed to the toxins through water based recreation so it is important to know what current measures are implemented and the state of public knowledge of cyanobacteria in the Simcoe/Muskoka region of Ontario. The full health implications of cyanobacterial exposure are not yet known and the methods for detecting and removing cyanobacteria from water bodies are not always feasible (Chorus and Bartram, 1999; Funari et al., 2017). Accurately tracking cyanoblooms is a challenge and a large number of waterbodies are not regularly monitored (Dellinger et al., 2017). Presently the most cost effective and efficient method of preventing cyanobacterial exposures and related illness is public education in order to recognize and avoid suspected cyanoblooms (Su et al., 2012; Qin et al., 2015).

Health Canada issued the most recent Guidelines for Canadian Recreational Water Quality in 2012 (Health Canada, 2012). The guidelines emphasize the importance of adequate dissemination of information about recreational water quality in preventing illness and outline the steps that should be taken in unsafe conditions. The Medical Officer of Health issues swimming advisories and relevant information is disseminated to the public through signs at affected locations, web site updates, and media releases (Health Canada, 2012). The Ontario Ministry of the Environment and Climate Change (OMOECC), the Ontario Ministry of Natural Resources and Forestry (OMNRF), the conservation authority, and the local municipality should be involved in investigating and managing the adverse event (Health Canada, 2012). However, it is unclear whether the guidelines are effective in educating the public about the health concerns of cyanobacteria and the prevention of adverse health events (Funari et al., 2017). Additionally, the guidelines have been criticized for basing the recommended practices on out of date data from adults when the most common exposures are amongst children (Schafer et al., 2020; Neilsen and Jiang, 2020; Funari et al., 2017).

The study location consisted of Simcoe County and Muskoka District in South Central Ontario. The area is 11 333 km^2 and has a permanent population of approximately 540 000 people with an estimated seasonal population increase of more than 170 300 people annually (County of Simcoe, 2014; District of Muskoka, 2016; County of Simcoe EDO, 2016). The region is a popular area with cottagers and tourists as there are more than 1 600 lakes including a large portion of the Trent-Severn Waterway. The largest lakes in the region include the southern tip of Georgian Bay, Lake Simcoe, and Lake Couchiching. Recreation from Lake Simcoe alone generates over $200 million per year for the local economy (Lake Simcoe Region Conservation Authority, 2016).

This study examined what residents and visitors to Simcoe/Muskoka knew about cyanobacterial blooms and how exposure can affect human health. Several lakes in the study region experience annual cyanoblooms, but blooms have recently become more frequent and severe (Dellinger et al., 2017). This study aimed to evaluate the accuracy and utility of the information that is presented in the news media in and around the study region about cyanoblooms and to assess what knowledge about cyanobacteria and the associated health effects was retained by visitors and residents in the Simcoe/Muskoka region and their attitudes about current practices.

3. Methods

3.2 Ethics

The study received ethics review and approval from the Laurentian University Ethical Review Board #6013940 (Appendix C).

3.3 Study Design

The study was a convergent parallel mixed method design that used both quantitative and qualitative approaches to gain a more complete understanding of the multiple factors that influence human decision making and health behaviours (Shoonenboom and Johnson, 2017). The qualitative portion consisted of a content analysis of news media articles about cyanobacteria. The quantitative portion consisted of a cross-sectional survey of the general population regarding participants' knowledge of cyanobacteria and its potential health effects. The benefits of this design were that by analyzing both what people knew and what information they had available to them may reveal how effective educational information may be. The quantitative part of the study provided information about what participants knew, while the qualitative part analyzed the information that the participants received. In this way, issues with the dissemination of information, the translation of the individual into understanding, and the application may be identified and thus targeted more effectively.

3.4 Rationale

Online news media was chosen as the focus of this research as many print, radio, and television news media organizations will also post their content online and many of the local news media outlets have moved their distribution to online media exclusively. Van de Waal and colleagues (2024) used the volume of search engine queries for cyanobacteria to indicate public awareness of cyanoblooms and news articles as some of the most common results of such queries. The Health Canada guidelines specify that information pertaining to water quality be disseminated through local news media (Health Canada, 2012). Articles meeting the study criteria were examined and evaluated based on a coding system developed by the researcher and informed by existing academic literature, the Social Cognitive Theory, and preliminary examinations of news media articles. The study focused solely on the information that was provided and not the way that it was delivered.

Survey questions were informed by the literature based on the Social Cognitive Theory developed by Bandura (Bandura, 1989). The Social Cognitive Theory is based on the premise that behavioural change is made possible by a personal sense of control; people who believe that they are able to control their actions to a desired end will attempt to do so (Luszczynska and Schwarzer, 2005). The survey (Appendix B) consisted of 42 questions in multiple choice, true and false, short answer, sliding scale, and drop down menu questions.

3.5 Inclusion and Exclusion Criteria

To be included in the sample, a news media article needed to focus primarily on cyanobacteria or blue-green algae. The articles that were included had to be posted by a news media organization that included the Simcoe/Muskoka region in its online distribution area. National and international stories were included as long as the media was commonly distributed in Simcoe/Muskoka through online presence. The research aimed to examine knowledge presented those living full-time in the study area, and those who visit the study area. Articles published between January 1st 2013 and May 1st 2019 were eligible to be included in the sample. The time frame for article inclusion was chosen to coincide with the information that was most relevant during the recruitment of survey participants to better clarify the information in both aspects of the study. The first 100 articles meeting the criteria, identified as the most relevant by Google, were included in the sample.

For the survey; individuals who lived in, or visited the Simcoe/Muskoka area, could read and write in English, and were 16 years of age or older at time of recruitment, were eligible to participate. It was important to include visiting non-residents in the survey as the study area is popular with cottagers and tourists who may be exposed to information different from what is available to residents. The survey was offered in English as it is the language most commonly spoken in the area. Children under 16 were excluded, as they typically depend on a parent or guardian to assess the safety of a water body for swimming.

3.6 Search Procedure

The news media articles were gathered using the Google search engine. The search terms used were: “blue-green algae Simcoe Muskoka”, “blue-green algae Simcoe”, “blue green algae Muskoka”, “cyanobacteria Simcoe Muskoka”, “cyanobacteria Muskoka”, and “cyanobacteria Simcoe”. These search terms were chosen as they were broad enough to encompass many articles about the topics using the most commonly known terminology while also targeting the specific area under consideration. The ‘most relevant’ sorting setting was used because it is the default setting that would be most commonly used in searches by the general public. The goal was to find and include the articles that would be most easily and widely accessed by the general public. Articles behind pay walls were excluded as individuals are less likely to read such articles. These methods were chosen because people who have not experienced a cyanobloom before are most likely to get information about cyanobacteria through browsing of news media via search engine query.

3.7 Recruitment

The study also involved completion of a survey of individuals who lived in, or visited, the Simcoe/Muskoka area of South Central Ontario, Canada between September 21st 2018 and March 31st 2019. Participants were recruited using snowball sampling. Online recruitment was initiated through friends, family, and two community musical groups who were invited to participate in the survey through direct email, social media links, or in person by the researcher. Participants contacted online were invited to pass the survey link to their own friends and family. In-person recruitment included five, six hour sessions of recruiting participants at two Farmers' Markets located in Barrie and Orillia. Participants completed a paper copy of the survey at the market table or provided a link to the online survey tool. Surveys completed online were via direct input into a form on Laurentian University's secure REDCap server (Harris et al., REDCap, 2009) or in person at the Orillia and Barrie Farmers' Markets. Paper copies were then transcribed to the online survey form by the researcher. This method allowed for a larger sample while accommodating individuals uncomfortable using computers.

3.8 Coding

The coding key (Appendix A) was designed to evaluate the article based on the presence or absence of key pieces of information for informing health behaviour decisions (e.g., description of a cyanobloom, route of exposure, etc.). An information item was considered present if any mention had been made about the topic in the article. Each article was assigned a score out of 100 based on how many of the key information pieces were present and the researcher's assessment of the quality of the article and its usefulness in providing information. Article quality was judged on the clarity of articulation and the amount of detail that was included. An associate recoded a random selection of articles and drew the same conclusions from the articles that the researcher had and there was minimal discrepancy between the coding and the recoding.

3.9 Survey Data

The researcher entered surveys completed on paper into the REDCap (version 9.1.0: Harris et al., REDCap, 2009) survey portal and each were assigned a number so that an associate could perform rechecking. All data were double checked for accuracy at the time of initial input and a random selection of ten surveys were later rechecked by an associate and the results were compared. The comparison revealed an error rate of less than 4%. Data were kept on the secure Laurentian REDCap (Harris et al., REDCap, 2009) server with no individual identifying information.

3.10 Statistics Analysis

Basic statistics (e.g., frequencies, percentages, means, standard deviations, and cross tabulations) were performed automatically by the REDCap (Harris et al., REDCap, 2009) analysis tools. Multiple regression analysis was performed using SPSS (IBM 2019, v 25) with a 95% confidence interval. Multiple regression analysis included information source, types of water ways used, age, gender, and frequency of water use as predictor variables to determine whether those activities had any effect on a participant's confidence in their ability to identify a potentially harmful cyanobloom.

3.11 Results

The survey resulted in 110 responses with 39 (35%) resulting from online survey completion and 71 (65%) from paper completion. The majority of participants (65%, n=71) were a result of recruitment at Farmers' Markets. Selection bias was possible as people who attend Farmers' Markets may be more environmentally conscious than people who do not attend Farmers' Markets but this bias did not appear in the data. The friends and family portion of the sample was comprised of people from various backgrounds and there was likely no selection bias in that part of the sample.

Residents of the study region made up 83.6% of the survey sample, while non-residents accounted for 10.9%, and 5.4% declined to answer. Non-resident visitors may increase the region's population by aproximately 23% annually. The lower non-resident percentage in the sample was likely due to the data collection during the winter when visitor numbers were lower.

The survey sample group self-identified as female 66.7% and 29.7% male, and the remaining 5.5% identified as other (i.e., preferred not to say, declined to answer, or other gender) (Table 1). People between the ages of 46 to 65 years were the most prevalent age group in the sample (40.5% of the sample). No statistically significant differences in the responses observed between males and females, age groups, or any other characteristics were assessed. The level of knowledge about cyanobacteria appeared to be relatively consistent across the population. This suggested that no particular group received more or less information.

Analysis of news media showed a wide range in the quality of the articles presented to inform the public. The researcher assigned a mark out of 100 for the article's usefulness in providing information that could help prevent exposure and illness. This designation was ultimately quite subjective, and although the interpretation of just one researcher was based on knowledge about current practices and the health effects of cyanobacterial exposure. On average, the sample of articles (Appendix A) was rated at 50.3 out of 100 for the amount and quality of the information provided. A rating of 100 represented the information that the researcher deemed the basic information necessary to inform health decisions.

News media, including online, television, and radio news, was the preferred source of information about recreational water quality, with 71.8% of survey respondents reporting using it as their primary source of information. Just over half (50.9%) of participants noted that they utilized beach postings and 44.5% reported that they used word of mouth as a source of information. Additionally, 8.2% of participants reported not receiving information about water quality from any source. The results of the survey and article analysis indicated that news media was the preferred information source but it only provided about half of the information necessary to make informed health decisions.

The majority of survey respondents (87.3%) reported participating in recreational water activities in the study area which indicated that the target audience represented a large proportion of the sample (Table 2). Participants were split into three groups based on their frequency of use of recreational waters with the light users (43%) engaging in recreational water use for 1 to 10 days a year, the moderate users (16.4%) engaging during 11 to 20 days per year, and heavy users (29.1%) engaging in recreational water activities for 20 or more days per year. There were no statistically significant differences in the results between more frequent or less frequent users of waterbodies for recreation. When asked about their primary reasons for recreational water use, many participants cited swimming to cool off on hot days (21.8%, n = 24) or simply for enjoyment (54.5%, n = 60).

A number of participants (n= 12, 11.5%) reported being unaware of the type of recreation area that they utilized (i.e., publicly managed, privately managed, unmanaged). This suggested that many people may attend swimming areas that are not subject to regular inspections for cyanobacteria. This highlighted the importance of providing easily accessible and widely available information about what indicators to look for when determining whether a water body is safe for recreational use. Only 13% of the articles mentioned who should be contacted if a person suspects that a bloom is present in an area. Given that routine monitoring is not done as frequently, or at all, on some lakes, people must be given the tools to both identify a potential cyanobloom, and the information on who should be contacted to verify the presence of cyanobacteria and notify other users of the affected waterbody.

When asked what signs indicate a cyanobloom in the area, 30% of survey participants indicated that they did not know. Only 33% of articles examined indicated how to identify cyanoblooms. While 61% of articles provided an image of what cyanobacterial blooms can look like, the same image was often used for multiple articles which does not account for the variability in bloom appearance. As most blooms are first identified by visual examination, it is important to include examples of what blooms look like so that people have a frame of reference. A written description of what to look for could also be included to improve the ability to identify blooms in conditions other than those pictured.

Participants were asked to rate their confidence in their ability to identify a cyanobloom with the average rating being 21.0, (s.d. 22.7) out of 100 (Table 3). Even participants who were able to identify the signs of a cyanobloom did not have confidence in their ability to do so. 38% of articles mentioned factors that can contribute to cyanoblooms. Increasing knowledge of the conditions that contribute to cyanoblooms may help people be prepared to identify possible blooms. This lack of confidence was also exhibited in questions that presented participants with more general statements about the nature of cyanobacteria and asked to identify whether the statement was true or false. Participants identified the statements with the overall average of all true and false question responses being 73.3% correct but their overall confidence ratings were still low.

Additionally, people must be well informed of what steps to take to avoid contact with cyanobacteria but only 49% of articles included this information. This commonly included reference to avoiding swimming in, or drinking, water from affected areas, but few articles noted that fish from contaminated waterbodies should not be eaten and even fewer noted and that contaminated water should not be used for irrigation or that boiling the water would not make it safe. Only 25% of news media articles revealed that a beach found to have dangerous levels of cyanobacteria will have signage posted on the beach. Survey participants were asked to rate their likelihood of engaging in recreational water use during a swim advisory. The average rating was 11.5 (s.d. 19.7) indicating that most (71.0%, n=78) participants would refrain from entering the water during an advisory but there were three (2.7%) respondents who stated that they were very likely to engage in recreational water use during an advisory. 2.7% (n=3) noted that while they would not swim during an advisory they would still canoe or kayak.

Some details about symptoms associated with cyanobacterial exposure were provided in 46% of the articles. This included any information about symptoms that were possible from exposure, regardless of whether the reported symptoms were likely. Survey participants were asked to choose from a list, any and all symptoms that cyanobacterial exposure could cause (Table 4). Nausea was the most commonly identified symptom with 57.8% of participants selecting it, followed by rash or skin irritation at 56.9% and headache and diarrhoea both at 46.8%. 36.7% indicated that they did not know what the symptoms were and did not make any guesses. These findings may indicate that even if participants had become ill after exposure to cyanobacteria, they may not have connected the symptoms with the potential cause.

A small number of participants (8.3%, n =9) reported that they had previously felt ill after recreational water use at some point in their life but were not asked to attribute their illness to any particular causative factor. The most common symptoms reported were skin rash/irritation (5.6%, n=6), and earache (5.6%, n=6). A subset (5.5%, n=6) of those who reported illness reported seeking treatment for it. While the sample size was very small, this suggested that reports of recreational water borne illness that rely on individuals seeking medical care may not capture the full number of people who may have been affected.

Survey participants were asked to rate their levels of concern using a scale that provided a numerical score out of 100, with 0 corresponding to the label 'unconcerned' and 100 representing 'extremely concerned' about selected topics (Table 3). Participants rated their concern for environmental aspect of water quality as the highest with the average rating being 75.8 (s.d. 26.3). Participants' concern about drinking water quality was on average rated 74.6 (s.d. 29.6). Concern about recreational water quality was rated 66.1 (s.d. 28.6). Biological contaminants, including bodily fluids, and animal waste had an average rating of 80.5 (s.d. 25.6). Cyanobacteria and E. coli were rated with a similar level of concern with ratings of 71.7, (s.d. 28.34) and 71.4, (s.d. 28.1), respectively. These results indicated that the sample was fairly concerned about all aspects of water quality, with cyanobacteria being of nearly equal concern to better-known aspects of water quality. It was possible that people were rating cyanobacteria as being of greater concern because it was a lesser known issue or because they were thinking about it more because the topic of the survey influenced their perception.

3.12 Conclusion/Discussion

The variation in the quality of information in news media suggested that the media could do more to effectively communicate details about cyanobacteria. The inconsistent quality may also indicate that people who relied on the media for information lacked the knowledge needed to take proper prevention measures during a cyanobacterial bloom. This was reinforced by the survey findings that showed that participants had low confidence in their knowledge of cyanobacteria. Most participants correctly identified suitable symptoms when provided a list but even though they may have picked at least some of the symptoms, they did not have confidence in their ability. The 'I Don't Know' option was often selected by a large part of the sample even when other symptoms had been selected, suggesting that the participants either lacked confidence in their selections or they had guessed.

In the context of minimal information provided in news media, this suggests that people may be acquiring information from another source or that they were guessing at the correct answers or using common sense to answer some questions rather than knowledge and understanding.

There was no significant difference between the knowledge of those who reported receiving information about recreational water safety and those who did not. This may suggest that current use of news media to distribute information about cyanobacteria may not significantly affect the participants' ability to identify important health-related information about cyanobacteria.

The vast majority of articles were paraphrasing health unit press releases which all followed a specific template. By enhancing the template with more details on prevention and additional resources, health unit press releases could significantly increase the information shared through news media about cyanobloom exposure.

Given that cyanobacterial exposure can occur through routes other than those that people would commonly associate with water-borne illness, it is imperative that these exposure routes are well described in press releases. It's important to describe these routes pragmatically, recognizing the potential for exposure while noting that such occurrences are rare.

A large proportion of the sample rated the environmental aspect of water quality as being of concern. In recent years a campaign to improve the environmental water quality of a major lake in the region gained a large following which may have contributed to this high level of concern. No other studies to the researcher’s knowledge have assessed this aspect in other regions of Ontario to indicate whether these results are typical of the larger population.

Participants expressed similar levels of concern about contamination from cyanobacteria and fecal coliforms like *E. coli*. This suggests that although elevated *E. coli* levels are more commonly responsible for beach closures, cyanobacterial blooms, despite being less frequent, are viewed with equal seriousness. This perception may stem from the striking appearance of cyanoblooms, which contrasts with the less noticeable presence of elevated *E. coli*. Additionally, participants’ awareness that cyanobacteria was the focus of the research may have influenced their concern ratings.

3.13 Survey Results in Context

A study of this kind has never been undertaken in this region to the knowledge of the researcher. However, some of the results of this study can be related to the findings of research that studied different aspects of cyanobacteria and human health. A study conducted by Hunter and colleagues (2012) asked participants around Loch Leven, a lake in Scotland that saw frequent cyanoblooms, about their attitudes toward cyanobacteria and their beliefs about the health effects. Many attitudes observed in the study by Hunter and colleagues (2012) were reflected in this research, with participants acknowledging the importance of water quality but lacking strong knowledge about various factors and health effects. Many also expressed concern about the decline in water quality due to human activities. Another commonality between the two studies was that personal risk was not considered to be high, thus suggesting that there was little sense of immediacy for dealing with the issues posed by cyanoblooms. Other studies which focused on epidemiology of cyanobacterial illness mentioned similar opinions among their participants (Osborn et al., 2007; Pillotto et al., 1997; Stewart et al., 2006 a).

3.14 Results in Framework

This study used the Social Cognitive Theory as its theoretical framework to guide the questions that were used in the survey and the analysis of the news media articles. The SCT is based on the assumption of emergent interactive agency whereby the individual makes a causal contribution to their own motivations and actions within a system of triadic reciprocal causation (Bandura, 1989). Triadic reciprocal causation involves cognition, behaviour, personal factors, and environmental influences to operate as interacting determinants of behaviour (Bandura, 1989 a). This framework suggested that participants' lack of confidence in identifying information about cyanobacteria may result from limited information available in news media. According to this theory, the study's findings suggest that individuals who lack sufficient information or self-efficacy regarding cyanobacteria may struggle to make choices that lead to positive health outcomes.

3.15 Study Strengths and Limitations

This paper is the first of its kind to the knowledge of the researcher, thus delving into a yet unexplored aspect of cyanobacterial related public health. The study utilized survey data and news media articles to provide a wider view of the information available to participants and their retention capabilities. It showed a naturalistic representation of the efficacy of current information dissemination methods and illustrated areas for improvement.

The study was limited by the low response rates and low numbers of participants which might have resulted in selection bias. Thus, it is difficult to be sure that the observed trends represent the larger population as a whole. However, the study still provides valuable insights into how at least a portion of the population view cyanobacteria and where they obtained their information. This information may be generalized to other regions where similar information dissemination methods are utilized.

3.16 Study Implications

This research revealed that most news articles that focused on cyanobacterial occurrences had minimal information that would be relevant to understanding and avoiding illness caused by cyanobacterial exposure. This finding would suggest that in the future, more information about functional knowledge of cyanobacteria (i.e., what signs to look for, course of action to take in common circumstances, etc.) should feature more prominently in news reports about cyanoblooms. Given that most news media articles contained information taken directly from district health unit press releases, it may be helpful for the health unit to provide more information of that nature in their press releases. However, the findings from the survey portion of the study make that course less clear cut. The survey findings suggested that people have some knowledge of the risks of cyanobacteria, even though they have little confidence in their own knowledge. This, in the context of minimal information provided by media suggested that people may be acquiring information from some source or that they could be guessing at the correct answers or using common sense to answer some questions rather than knowledge and understanding.

While people may have done reasonably well in identifying some aspects of cyanoblooms that would be relevant to health, they were not necessarily basing their answers on knowledge and had little confidence in their answers. It is possible that this lack of confidence could either lead people to be more cautious when faced with a potential cyanobloom or lead to people engaging in risky behaviours due to ignorance. The survey revealed that current information dissemination methods do not appear to lead to greater public knowledge and ability to recognize a potentially harmful situation. It may be necessary to re-evaluate the current practices and adopt a new strategy such as newsletters sent to people via email or text who opt in to a service, and utilizing ad space on social media platforms to provide educational material, adding QR code with additional information on beach postings, or creating a game based app that uses health information as part of the game play. In order to find novel ways of reaching people in an age of technology, it may be beneficial to take an interdisciplinary approach and utilize the field of marketing as a means of getting people engaged with health information with the aim to give people both knowledge and the confidence to use it.

3.17 Future Research

The findings of this study suggest that people may have reasonably good knowledge, or possibly, be able to make reasonably good guesses as to the safety of a given water body and the symptoms of cyanotoxin poisoning. However as the sample did not demonstrate confidence in their answers it is unclear how this could affect illness incidence. Future research could determine the effect of confidence on illness incidence or the likelihood of exposure.

Another avenue of future study could be conducting focus groups with members of the public to determine what information they absorb from current information dissemination procedures and ask for input on how to improve the current methods and what new methods they would be receptive to.

3.18 References

Almeida, C., Gonzalez, S., Mallea, M., Gonzalez, P. (2012) A recreational water quality index using chemical, physical, and microbial parameters. *Environ Sci Pollut Res* 19: 3400 – 3411

Backer, L., Manassaram-Baptiste, D., LePrell, R., Bolton, B. (2015) Environmental data from Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007 – 2011. *Toxins* 7: 1048 – 1064

Backovic, D., Tokodi, N., Nikolin, B., Svircez, Z. (2020) Cyanobacteria – insidious foe of the skin? *Journal of Water and Health* 18.3.

Bandura, A. (1989) Social cognitive Theory. *Annals of Child Development* 6:1-60

Bandura, A. (1989 a) Human agency in social cognitive theory. *American Psychologist*. Vol 44, No 9. 1175-1184

Bennell, M., Joyce, A., Gardner, E., Frontenac, K., Majury, A. (2015) An evaluation of Southeastern Ontario recreational water quality. *International Perspectives.* 77:10 26-33

Bertani, I., Steger, C., Obenour, D., Fahnenstiel, G., Bridgeman, T., Johengen, T., Sayers, M., Schuchman, R., Scavia, D. (2017) Tracking cyanobacterial blooms: Do different monitoring approaches tell the same story? *Science of the Total Environment* 575: 294 – 308

Burnford, M., Carey, C., Hamilton, D., Huisman, J., Paerl H., Wood, S., Wulff, A. (2020) Perspecitve: Advancing the research agenda for improving understanding of cyanobacteria in a future of global change. *Harmful Algae,* 91.

Calado, S., Wojciechowski, J., Santos, G., Magalhes, V., Padial, A., Cestari, M., Assis, H. (2017) Neurotoxins in a water supply reservoir: an alert to environmental and human health. *Toxicon* 126: 12-22

Chapra, S., Boehlert, B., Fant, C. Bierman, V., Henderson, J., Mills, D., Mas, D., Rennels, L., Jantarasami, L., Martinish, J., Strzepek, K., Paerl, H. (2017) Climate change impacts on harmful algal blooms in U.S freshwaters: a screening level assessment. *Environmental Science and Technology*

Chorus, I., Bartram, J. (1999) Toxic cyanobacteria in water: A guide to public health consequences, monitoring and management. *E & FN Spon.* Suffolk.

Dellinger, J., Dorevitch, S., Faustman, E., Foldy, S., Takaro, T. 2017. Human health effects of cyanobacterial toxins in the great lakes region: A science and monitoring assessment. *International Joint Commision by the Health Professionals Advisory Board*

Drobac, D., Tokodi, N., Simeunovic, J., Baltic, V., Stanic, D., Svircev, Z. (2013) Human exposure to cyanotoxins and their effect on health. *Arh Hig Rada Toksikol* 64: 305 – 316

Funari, E., Manganelli, M., Buratti, F., Testai, E. (2017) Cyanobacteria blooms in water: Italian guidelines to assess and manage the risk associated to bathing and recreational activities. *Science of the Total Environment* 598: 867 – 880

Gandola, E., Antonioli, M., Traficante, A., Franceschini, S., Scardi, M., Congestri, R. (2016) ACQUA: Automated cyanobacterial quantification algorithm for toxin filamentous genera using spline curves, pattern recognition, and machine learning. *Journal of Microbiological Methods* 124:48-56.

Gaget, V., Almuhtaram, H., Kibuye, F., Hobson, P., Zamyadi, A., Wert, E., Brookes, J. (2022) Benthic Cyanobacteria: A utility-centered field Study. *Harmful Algae*. 133.

Geh, E., de la Cruz, A., Ghosh, D., Stelma, G. Bernstein, J. (2016) Sensitization of a child to cyanobacteria after recreational swimming in a lake. *J Allergy Clin Immunol* 137(6) 1902 – 1904.

Greenfield, D., Duquette, A., Goodson, A., Keppler, C., Williams, S., Brock, A., Stackley, K., White, D., Wilde, S. (2014) The effects of three chemical algaecides on cell numbers and toxin content of the cyanobacteria *Microcystis aeruginosa* and *Anabaenopsis sp. Environmental Management* 54: 1110 – 1120

Harris, P., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., Conde, J. (2009) Research electronic data capture (REDCap) – A metadata-driven methodology and workflow process for providing translational research informatics support, *J Biomed Inform*. Apr;42(2):377-81

Health Canada (2012) Guidelines for Canadian Recreational Water Quality, Third edition. Water, Air, and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Howard, M., Kudela, R., Hayashi, K., Tatters, A., Caron, D., Theroux, S., Oehrle, S., Roethler, M., Donovan, A., Loftin, K., Laughrey, Z. (2021) Multiple co-occurring and persistently detected cyanotoxins and associated cyanobacteria in adjacent California lakes. *Toxicon*

Huber, V., Wagner, C., Gerten, D., Adrian, R. (2012) To bloom or not to bloom: contrasting responses of cyanobacteria to recent heat waves explained my critical thresholds of abiotic drivers. *Oecologia* 169: 245 - 256

Huisman, J., Codd, G., Paerl, H., Ibelings, B., Verspagen, J., Visser, P. (2018) Cyanobacterial Blooms. *Nature Reviews: Microbiology*. 16.471.

Hunter, P., Hanley, N., Czajkowski, M., Mearns, K., Tyler, A., Carvalho, L., Codd, G. (2012) The effect of risk perception on public preferences and willingness to pay for reductions in the health risks posed by toxic cyanobacterial blooms. *Science of the Total Environment* 426: 32 - 44

Lake Simcoe Region Conservation Authority (2016) Lake Simcoe watershed. https://www.lsrca.on.ca/our-watershed Newmarket, Ontario

Lee, T., Rollwagen-Bollens, G., Bollens, S., Faber-Hammond, J. (2015) Environmental influence of cyanobacteria abundance and microcystin toxin production in a shallow temperate lake. *Ecotoxicology and Environmental Safety* 114: 318 – 325

Levesque, B., Gervais, M., Chevalier, P., Gauvin, D., Anassour-Laouan-Sidi, E., Gingras, S., Fortin, N., Brisson, G., Greer, C., Bird, D. (2017) Exposure to cyanobacteria: Acute health effects associated with endotoxins. *Public Health* 134:98-101

Lin, C., Wade, T., Sams, E., Dufour, A., Chapman, A., Hilborn, E. (2016) A prospective study of marine phytoplankton and reported illness among recreational beachgoers in Peurto Rico, 2009. *Environ Health Perspect* 124: 477-483

McGregor, G., Stewart, I., Sendall, B., Sadler, R., Reardon, K., Carter, S., Wruck, D., Wickramasinghe, W. (2012) First report of a toxin *Nodularia spumingena* (Nostocales/cyanobacteria) bloom in sub-tropical Australia.I phycological and public health investigations. *Int. J. Environ. Res. Public Health* 9: 2396 - 2411

Metcalf. J., Codd, G. (2020) Co-Occurrence of cyanobacteria and cyanotoxins with other environmental health hazards: Impacts and implications. *Toxins*. 12, 629.

Mrdjen, I. & Lee, J. (2018) Simple and practical on-site treatment of high microcystin levels in water using polypropylene plastic. *Journal of Environmental Science and Health, Part A*. 53(11): 1000-1005

Nielsen, M., Jiang, S. (2020) Can cyanotoxins penetrate human skin during water recreation to cause negative health effects? *Harmful Algae*. 98

Osborne, N., Shaw, G., Webb, P. (2006) Health effects of recreational exposure to Moreton Bay, Australia waters during a *Lynbya majuscula* bloom. *Environment International* 33 309 – 314.

Otten, T. and Paerl, H. (2015) Health effects of toxic cyanobacteria in U.S. drinking and recreational waters: Our current understanding and proposed direction. *Current Environmental Health Reports* 2: 75-84

Papadimitriou, T., Kormas, K., Dionysiou, D., Laspidou, C. (2016) Using H2O2 treatments for the degradation of cyanobacteria and microcystins in a shallow hypertrophic reservoir. *Environ Sci Pollut Res* 23: 21523-21535

Plaas, H., Paerl, H. (2021) Toxic cyanobacteria: A growing threat to water and air quality. *Environmental Science and Technology*. 55, 44-64.

Persuad, A., Paterson, A., Dillon, P., Winter, J., Palmer, M., Somers, K. (2015) Forecasting cyanobacterial dominance in Canadian temperate lakes. *Journal of Environmental Management* 151: 343 – 352

Pilotto, L., Douglas, R., Burch, M., Cameron, S., Beers, M., Rouch, G., Robinson, P., Kirk, M., Cowie, C., Hardiman, S., Moore, C., Attewell, R. (1997) Health effects of exposure to cyanobacteria (blue-green algae) during recreational water-related activities. *Australian and New Zealand Journal of Public Health* 21: (6) 562 – 566

Pitois, F., Vezie, C., Thoraval, I., Baures, E. (2016) Improving microcystin monitoring relevance in recreative waters: A regional case study (Brittany, Western France, Europe). *International Journal of Hygiene and Environmental Health* 219: 288-293

Qin, B., Li, W., Zhu, G., Zhang, Y., Wu, T., Gao, G. (2015) Cyanobacterial bloom management through integrated monitoring and forecasting in large shallow eutrophic Lake Taihu (China). *Journal of Hazardous Materials* 287: 356 – 363

Rastogi, R., Madamwar, D., Incharoensakdi, A. (2015) Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Frontiers in Microbiology* 6: 1254

Schafer. A., Yrastorza, L., Stockley, N., Harvey, K., Harris, N., Grady, R., Sullivan, J., McFarland, M., Reif, J. (2020) Exposure to microcystin among coastal residents during a cyanobacteria bloom in Florida. *Harmful Algae*. 92

Shoonenboom, J., and Johnson, R. (2017) How to construct a mixed methods research design. *Köln Z Soziol (2) 69:107 - 131*

Stewart, I., Webb, P., Schluter, P., Shaw, G. (2006 A) Recreational and occupational field exposure to freshwater cyanobacteria – a review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. *Environmental Health: A Global Access Science Source* 5:6.

Stewart, I., Webb, P., Schluter, J. Fleming, L., Burns, J., Gantar, M., Backer, L., Shaw, G. (2006 B) Epidemiology of recreational exposure to freshwater cyanobacteria – and international prospective cohort study. *BioMed Central Public Health* 6:93.

Su, Y., Liu, H., Yang., J. (2012) Metals and metalloids in the water-bloom-forming cyanobacteria and ambient water from Nanquan Coast of Taihu Lake, China. *Bull Environ Contam Toxicol* 89: 439 - 443

Svircev, Z., Drobac, D., Tokodi, N., Vidovic, M., Simeunovic, J., Milandinov-Mikov, M., Baltic, V. (2013) Cancer in Serbia and possible connection with cyanobacterial blooms. *Journal of Environmental Science and Health,* Part C, 31:181 – 200.

Van de Waal, D., Gsell, A., Harris, T., Paerl, H., de Sederpont Domis, L., Huisman, J. (2024) Hot summers raise public awareness of toxic cyanobacterial blooms. Water Research. 249:120817.

Watson, S., Zastepa, A., Boyer, G., Matthews, E. (2017) Algal bloom response and risk management: on site response tools. *Toxicon.* 129.

World Health Organization (WHO) (2003) Guidelines for safe recreational water environments. Volume 1: Coastal and fresh waters. Geneva, Switzerland.

Wolf, D., Georgic, W., Klaiber, H. (2017) Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. *Journal of Environmental Management* 199:148 – 157

Wood, R. (2016) Acute animal and human poisonings from cyanotoxin exposure – A review of the literature. *Environment International* 91:276-282

Wynn, T., Stumpf, P. (2015) Spatial and temporal patterns in the seasonal distribution of toxic cyanobacteria in Western Lake Erie from 2002 – 2014. *Toxins* 7: 1649 – 1663.

Tables

Table 1 Gender and Age Distribution Survey Sample

Gender	% of Sample	N
Male	29.6	32
Female	66.7	72
Other	0.9	1
Prefer not to say	2.8	3
Missing	1.8	2
Age Distribution	**% of Sample**	**N**
16-25	11.3	11
26-45	26.4	28
46-65	40.5	40
66-85	21.7	23
Missing	3.6	4

Table 2 Recreational Activities and Days Per Year Engaging

Activity	% of Sample	n
Swimming	79.1	87
Wading	54.5	60
Canoeing	39.1	43
Kayaking	36.4	40
Fishing	23.6	26
Water Skiing	1.8	2
Paddle Boating	12.7	14
Snorkeling	10.9	12
Number of Days Engaged in Recreational Water Activities per year	**% of Sample**	**n**
0	**10.9**	**12**
1-5	24.5	27
6-10	19.1	21
11-15	6.4	7
16-20	10	10
21-25	2.7	2.7
>25	26.4	29

Table 3 Level of Concern rating out of 100 scale ascending intensity

Concern	Mean Level of Concern Rating out of 100	Standard Deviation	Missing n (%)
Recreational	66.1	28.6	1 (0.9)
Drinking Water	74.6	25.6	0 (0)
Environmental	75.8	26.3	0 (0)
Bacteria (E. coli)	71.4	28.1	0 (0)
Cyanobacteria	71.7	28.3	1 (0.9)
Self-Reported Likeliness to Engage in Water Use During Advisory	**Mean Level of Likeliness out of 100**	**Standard Dev**	**Missing**
Stated Likelihood	**11.5**	**19.7**	**105 (5 {4.5%} missing)**

Table 4 Self reported illness events

Reported Illness After Water Use	% of Sample	n
Yes	8.3	9
No	85.3	93
Unsure	6.4	7
Missing	0.9	1
Sought Medical Care	**% of Sample**	**n**
Yes	**5.5**	**6**
No	**15.6**	**17**
Don't Know	**2.8**	**3**
Not Applicable	**76.1**	**83**
Missing	**0.9**	**1**
Symptoms of Illness after Water Use	**% of Sample**	**n**
Skin or Rash	5.6	6
Ear	5.6	6
Respiratory/Sinus	0	0
Nausea	0	0
Diarrhea	0	0
Eye	0	0
Vomiting	0	0

Chapter 4

4.0 Study Conclusion

4.1 Study Summary

This study assessed current knowledge of cyanobacteria in relation to recreational water use and health for members of the general population of residents and visitors to (n=110) Simcoe County and Muskoka District in Ontario, Canada, using a population based survey and a concurrent analysis of 100 news media articles available in the region for the period from January 1st 2013 to May 1st 2019.

The analysis revealed that news media articles largely lacked information that could be useful in preventing illness, such as cyanobloom appearance, measures that individuals can take to avoid exposure, and symptoms associated with exposure.

Survey questions were informed by the literature based on the Social Cognitive Theory developed by Bandura (Bandura, 1989). The Social Cognitive Theory is based on the premise that behavioural change is made possible by a personal sense of control. People who believe they can control their actions to a desired end will attempt to do so (Luszczynska and Schwarzer, 2005).The core concepts of knowledge, self-efficacy, outcome expectations, goals, and facilitators/impediments represent factors that affect how a person makes a decision about engaging in a behaviour that can affect their health.

The survey revealed that while most people could identify some symptoms of cyanobacterial exposure and some feature of a cyanobloom, very few participants had more than minimal confidence in their knowledge or identification abilities.

4.2 News Media Evaluation Summary

Overall, the content analysis showed a wide range in the quality of the articles presented to inform the public. Some articles provided detailed information about what cyanobacteria are, how they can affect the health of the individual and the environment, how to avoid contact, and how to reduce the frequency of blooms in the future. Most articles provided a mix of the information, but only emphasizing one or two aspects. Several articles provided insufficient information to educate the individual about any of the aspects investigated. This wide variation suggested that there is more that the media can do to disseminate health-related and other useful information about cyanobacteria.

It was also noted that most of the information that was contained within the articles was taken directly from district health unit press releases. These press releases followed a standard template that was reused for multiple incidences of cyanobloom occurrences, thus it would be easy to update the template with more information that could be disseminated.

Only 25% of articles noted that a beach with dangerous levels of cyanobacteria will have signage at the beach notifying people of the fact. If people are not made aware of the signage system, there is potential to reduce compliance with the signage.

Forty percent of the articles made some attempt at describing the routes by which people can be exposed to cyanobacteria. This information is key to preventing exposure as people may not realize for example that dermal contact is sufficient to cause an adverse health outcome; nor would many people realize that inhaling aerosolized water with cyanobacterial contamination could cause an adverse reaction. Since cyanobacterial exposure can occur through routes not typically associated with waterborne illnesses, it is essential to clearly describe these exposure pathways. It is also important to describe these routes pragmatically, acknowledging the potential for exposure while emphasizing that such occurrences are rare. While caution is advised, there is no need for panic.

Forty-nine percent of articles included some information about how to avoid contact with cyanobacteria. This included any reference about avoiding swimming in, or drinking water from affected areas. However, few articles mentioned that fish from contaminated water should not be eaten or that boiling the water would not make it safe for use. This information is crucial for preventing illness, as it provides essential guidance on the actions to avoid different exposure routes.

Some detail about symptoms associated with cyanobacterial exposure was provided in 46% of the articles. This included any information about symptoms that were possible from exposure, regardless of whether the reported symptoms were common. According to the Health Belief Model proposed by Rosenstock, people are more likely to engage in a preventative behaviour if the illness is severe and the effects are long lasting. Thus people need to be aware of the effects of cyanobacterial exposure to want to avoid them (Mikhail, 1989).

Only 33% of the articles examined offered guidance on identifying cyanoblooms, while 61% included an image of what cyanobacterial blooms look like, often using the same image across multiple articles. As most blooms are first identified by visual examination, it is important to include examples of what blooms look like so that people have a frame of reference.

Additionally, blooms can look quite different depending on the conditions of the water body; it would be useful to include images that describe the range of appearances that cyanoblooms can take. This could include a written description of what to look for to improve the ability to identify blooms in conditions other than those pictured. Only 13% of the articles mentioned who should be contacted if a person suspects that a bloom is present in an area. Given that routine monitoring is not done as frequently, or at all, on some lakes, it is essential that people are given the tools to both identify a potential cyanobloom, and the information on who should be contacted to verify the presence of cyanobacteria and notify other users of the affected waterbody.

Just 24% of articles indicated how cyanobloom occurrences can be reduced. While there are no ways to guarantee that blooms will not occur again in any given water body, reducing eutrophication can reduce the nutrient supply contributing to bloom dynamics. People must know how they can make an active difference in the health of their local waterbodies particularly as reducing eutrophication of waterways involves coordinated efforts on the part of local land owners and the municipality to reduce nutrient loads and runoff.

Thirty-eight percent of articles mentioned factors that can contribute to cyanoblooms. Knowing the conditions that contribute to cyanoblooms can help people be prepared to identify possible blooms and have testing and confirmation done sooner. For example recreational boaters who are most likely to frequent warm and sheltered bays where blooms may begin and are less accessible from land may be able to notify authorities of a potential bloom earlier if they are knowledgeable about the factors that favour bloom growth.

Only 17% of articles examined discussed the environmental impact of cyanoblooms. The cyanoblooms cause additional deleterious effects on the lives of people who reside near or use the waterway; severely impacting the fishing and tourism industry, providing a livelihood and recreational enjoyment for many who live and work in the region. The economic impact of cyanoblooms has not been studied in the Simcoe/Muskoka area specifically yet it has been extensively studied in other regions including the south shore of Lake Erie. Additionally, as cyanoblooms exacerbate the conditions which give rise to them, once a waterbody has experienced a bloom, it is more likely to experience more blooms in subsequent years causing a compounding effect.

The researcher assigned a mark of 100 for how useful each article was, providing information that can help prevent exposure and illness. This designation was ultimately quite subjective, and based on the interpretation of one researcher only, but was based on knowledge about current practices and health effects of cyanobacterial exposure. On average, the sample of articles was rated at 50.3 out of 100 in terms of the amount and quality of the information they provided. Articles that included detailed information about cyanoblooms, how to identify them, and how to avoid exposure and report bloom sightings were rated higher than articles that merely noted that a specific water body was experiencing a bloom and should be avoided.

The average rating of 50.3 out of 100 coupled with the generally low results of each question showed that there is significant room for improvement in the quality and amount of information conveyed through news media. News media has a wide reach and ability to quickly and effectively convey important information to the people who would benefit from it. The onus is not entirely on the news media outlet to find the correct information to disseminate. Of the 100 articles examined, 49 of them (49%) were noted to be a direct paraphrase or copy of a health unit press release. The researcher noted that health unit press releases were standardized form letters with only the affected location changing from event to event. Each press release provided the same limited information about cyanobacteria and some basic measures for avoiding exposure. As the press release information made up a significant amount of the information that was conveyed in the news media, improving the standard press release form letter could significantly increase the number of news media articles with information detailed enough to aid the population in avoiding cyanobacterial exposure.

Examining the press releases revealed that more detailed information is key to informing public health behaviours, and the news media can then disseminate that information. It would not be significantly more work to alter the existing press release form currently used to include the additional information (i.e., signs of a bloom, symptoms of exposure, links to further information, etc.) evaluated in this examination.

Overall, the content analysis of news media articles revealed that there was a wide range in the amount and quality of the information presented in articles. Any single article may not provide adequate information to make informed decisions about steps to take to avoid contact with cyanobacteria.

4.3 Survey Summary

Survey results (n=110) revealed that most people could correctly identify some of the health effects of cyanobacterial exposures, with 57.2% correctly identifying nausea as a common symptom of cyanotoxin poisoning. However, the average rating of their confidence in their ability to identify cyanobacterial blooms was very low with an average confidence rating of 21.1 (s.d. 22.7) out of 100. Unexpectedly, those who reported receiving information about cyanobacteria from news media did not perform any better on the survey about cyanobacterial knowledge compared to those who reported receiving no information from any source and there were no statistically significant differences between any demographic groups of participants.

The recruitment consisted primarily of people who attended Farmers' Markets (65%) and friends and family and acquaintances of the researcher (35% of sample). Selection bias was possible as people who attend Farmers' Markets may be more environmentally conscious than people who do not attend Farmers' Markets, but this bias was not evident from the data.

The sample consisted of a greater proportion of women than men, which may be due to selection bias as most individuals in the researcher's social groups were female and more females than males shopped at Farmers' Markets. While it would have been useful to have a larger representation of young adults who are most likely to engage in recreational water activities, a large percentage of participants reported frequent and heavy engagement in recreational water use which still allowed the sample to be useful. It is unclear how selection bias may have affected the data as there were no statistically significant differences in the responses observed between males and females, age groups, education level, or any other characteristics assessed. The level of knowledge about cyanobacteria appeared to be relatively consistent across the population.

A small number of participants (8.3%, n = 9) reported feeling ill after recreational water use. However, they were not asked to identify a causative agent the most common symptoms reported were skin irritation (5.6%, n=6) and earache (5.6%, n=6). Among those who fell ill, a subset sought medical treatment (5.5%, n = 6). These results are consistent with previous epidemiological studies on cyanobacterial exposure (Pilotto et al., 1997; Stewart et al., 2006a;

Osborne et al., 2007).While the sample size was very small, this research corroborated conclusions drawn by other researchers that reports of recreational water borne illness that rely on individuals seeking medical care may not capture the full number of people who may have been affected (Pilotto et al., 1997; Stewart et al., 2006a; Osborne et al., 2007).

Many people rated the environmental aspect of water quality as being of concern. The elevated level of concern from an environmental perspective may reflect both the global and local increase of awareness about the degradation of the environment. Concerns about recreational water quality were slightly lower than for drinking water and environmental quality as a whole. This could be due in part to the lower level of impact on wellbeing that recreational use has compared to drinking water but could also be due to a lack of focus in the media on recreational use.

Contamination by cyanobacteria and fecal coliforms such as *E. coli* were given a similar rating in the level of concern. This may indicate that while elevated *E. coli* levels are more often the cause of beach closures, cyanobacterial blooms, despite their lower frequency of occurrence are given similar concern. This could be due in part to the more compelling visual of a cyanobloom compared to elevated levels of *E. coli* which do not have such a remarkable appearance. The similarity could also be due to a lack of familiarity with cyanobacteria, which leads people to be more comfortable with the more familiar threat of *E. coli*.

When asked whether they personally would swim during an advisory many (71.0%, n=78) indicated that while they would not swim, 2.7% (n=3) indicated that they would not swim but would still engage in canoeing and kayaking. Of greatest concern were the three respondents (2.7%) who indicated that they would likely swim even during a swim ban and reported to have previously done so. In the question asking participants to relate their primary reasons for engaging in recreational water use, many participants (21.8%, n=24) noted that they swim to cool down on hot days or simply for enjoyment (54.5%, n=60).

People primarily received their information from news media (87.3%, n=96). Participants may gain knowledge from other sources that they did not report, or more likely, they used common sense or guessing. Most people were able to correctly identify common symptoms of cyanobacterial poisoning when provided a list but, even though they may have picked at least some of the symptoms, they did not have confidence in their choices. The 'I Don't Know' option was often selected by a large part of the sample, suggesting that the participants either lacked confidence in their selections or had guessed. This again leads to questions of how much people really know.

There was no significant difference between the knowledge about those who reported receiving information from news media and those who did not report receiving information. This may suggest that current use of news media to distribute information about cyanobacteria may not be a significantly effective method to enable people to confidently identify, nor determine their personal or environmental health risks of cyanobacteria.

4.4 Results in Framework

This study used the Social Cognitive Theory as its theoretical framework to guide the questions that were used in the survey. The SCT is based on the assumption of emergent interactive agency whereby the individual makes a causal contribution to their own motivations and actions within a system of triadic reciprocal causation (Bandura, 1989). Triadic reciprocal causation involves cognition, behaviour, personal factors, and environmental influences to operate as interacting determinants of behaviour (Bandura, 1989 a). The SCT is a multifaceted causal structure in which self-efficacy beliefs operate with goals, outcome expectations, perceived environmental impediments and facilitators in regulating motivation and behaviour (Bandura, 2004). The SCT includes the core determinants, the mechanisms through which they work, and the optimal translation methods into practice (Bandura, 2004). The core determinants are *knowledge* of health risks, the perceived *self-efficacy*, *outcome expectations* or costs and benefits of health behaviours, *goals* for healthy behaviour, and the perceived social and structural *facilitators or impediments* to their success (Bandura, 2004).

Valuable knowledge is imparted within a social context (Bandura, 1989 a). For information to be passed most efficiently and retained as knowledge, a suitable social context must be utilized. This concept is integral to this research as it helped identify what social pathways (news media, peer relations, social media, district health unit bulletins, etc.) provided the most accurate knowledge, the best retention, and the best behaviour results. The finding that most people surveyed did not report having received information from many of the pathways described suggested that they were not receiving much information from them and that likely, they were utilizing common sense or guesses to inform their answers to survey questions. This finding may also imply that the social context in which cyanobacterial information is disseminated is ineffective for information retention.

The core concept of self-efficacy is central to the findings of the study because a large part of decision making can be attributed to the person's self-efficacy or confidence in their ability to identify cyanoblooms and safe waterways for recreation. The low confidence reported in the sample can suggest several potential decision outcomes through the SCT: people may err on the side of caution and refrain from engaging in recreational water use because they are not sure of their ability to identify a potential cyanobloom and they value the outcome of lack of illness above the risk incurred by engaging in the activity. The lack of confidence in identification ability could also lead to a person engaging in recreation during a threat because they value the immediate pleasure of recreation over the possibility of illness or their lack of understanding of the threat does not allow them to make an informed decision. It is possible that further research could determine more factors and responses to the situation which could be useful in determining strategies to prevent illness.

Personal factors shape the interaction with social factors and vice versa (Bandura, 1989 a). People evoke different social reactions based on their characteristics (Bandura, 1989). An individual’s personal factors will affect their outcome expectations for a given action. This aspect was evident in the answers that participants provided when asked about their opinions of the safety of engaging in recreational activity in water that was under an advisory. Some viewed the action as perfectly reasonable and something that they themselves would partake in while others viewed the action as reckless and ill-advised and a detriment to society. Personal factors also came into play in the interpretation of the research findings. Because of personal factors, it is difficult to determine how the low level of confidence in cyanobacterial identification ability will affect how people respond to a situation where their ability is tested. Low confidence in their ability could lead to disregard of their suspicions or to an increased level of caution because they are not certain of their own assessment. Thus, because of personal factors, it is challenging to draw implications about what the study’s findings mean for not only individuals but for the population as a whole.

4.5 Results in Context of Existing Literature

A convergent parallel study has not been undertaken in the study area to the knowledge of the researcher. Svircev and colleagues (2017) noted that there were few epidemiological studies of cyanobacterial effects on human health, with most of the literature consisting of retrospective accounts of poisoning cases. Additionally, the studies conducted have occurred in various locations and conditions, making it challenging to identify commonalities due to the diverse contexts and study environments. Furthermore, this study focused on the public health and perception aspects of cyanoblooms; features which are not often widely explored in pure epidemiological studies or retrospective accounts of illness occurrence.

However, some of the results of this study can be related to the findings of research that studied different aspects of cyanobacteria and human health. A study conducted by Hunter and colleagues (2012) around Loch Leven, Scotland, a lake that experienced frequent cyanoblooms, surveyed participants about their attitudes toward cyanobacteria and their beliefs about possible related health effects. Many of the attitudes observed in their study were mirrored in this study, with people noting that water quality was important to them but their knowledge of different factors and health effects were not necessarily good. Many expressed concern about anthropogenic decline in water quality. Another commonality between the two studies was that personal risk was not considered to be high, thus suggesting that there was little sense of immediacy for dealing with the issues posed by cyanoblooms. Other studies which focused on epidemiology of cyanobacterial illness mentioned similar opinions among their participants but did not go into detail (Osborn et al., 2007; Pillotto et al., 1997, Stewart et al., 2006 a).

Reif and colleagues conducted an epidemiological study of 125 participants in Florida during a cyanobloom and noted that participants who had achieved higher levels of education had fewer symptoms of cyanobacterial exposure (Reif et al., 2023). Analysis of the current study results did not show any significant difference in knowledge or confidence between those who reported higher levels of education and those who did not. This may indicate that people with higher levels of education are not avoiding exposure because they have higher levels of education or greater knowledge of cyanobacterial blooms but have some unknown confounding factor. This may also be an effect of the small sample sizes of both studies.

Van de Waal and colleagues (2024) studied search engine trends relating to cyanobacteria as an indicator of public knowledge about cyanobacteria. They found that online searches for information about cyanobacteria followed clear annual patterns with peaks during warm and wet seasons with 67 to 90% of searches during respective summer months and warmer summers coincided with more searches (Van de Waal, 2024). Van de Waal and colleagues' findings supported the premise that was used to guide the article examination portion of this research and supported the conclusion that improving the information provided in news media could potentially improve public knowledge. News media articles are often highly ranked results in search engine queries, and improving the quality of those articles could result in greater awareness and understanding of the health risks posed by cyanobacteria.

4.6 Study Strengths and Limitations

This study utilized survey data and news media articles to provide a wider view of the information available to participants and theirretention capabilities. It showed a naturalistic representation of the efficacy of current information dissemination methods and illustrated areas for improvement. The research was guided and informed by a conceptual framework that takes into account some of the complexities of motivation for health seeking behaviour such as knowledge, self-efficacy, and personal factors.

The study was limited by the low response rates online and low numbers of participants which might have resulted in selection bias. A potential contributing factor to the low recruitment and response rate was that the research timeline necessitated that data collection was conducted during the winter months when outdoor aquatic recreation was not in the forefront of people's minds. Online response rates may have been improved by offering a monetary incentive such as a small denomination gift card for each participant or each participant being entered into a draw for a single large denomination gift card. Unfortunately providing financial incentives was not feasible for the researcher. During the in-person recruitment sessions, prospective participants were offered candies or small baked goods regardless of whether or not they chose to complete a survey.

Because the sample size was small, it is difficult to be sure that the trends observed are representative of the larger population as a whole but the study still provides valuable insights into how at least a part of the population views cyanobacteria and how they obtained their information. This information can be generalized to other regions where similar information dissemination methods are utilized.

4.7 Study Implications

This research revealed that most news articles that focused on cyanobacterial occurrences had minimal information that would be relevant to understanding and avoiding illness caused by cyanobacterial exposure. This finding would suggest that in the future, more information about functional knowledge of cyanobacteria (i.e., what signs to look for, the variability of bloom appearance, the conditions that create cyanoblooms, course of action to take in common circumstances, etc.) should feature more prominently in news reports about cyanoblooms. Given that most news media articles contained information that was taken directly from district health unit press releases, it would have been more efficient for the health unit to provide more detailed information of that nature in their press releases. However, the findings from the survey portion of the study made that course less clear cut. The survey findings that suggested that people have some knowledge of cyanobacterial dangers regardless of their use of news media sources; however even when they demonstrated knowledge; they had little confidence in their self efficacy. In the context of minimal information provided by media, this suggests that people may be acquiring information from another source (which was not suggested by the findings) or that they were guessing at the correct answers or using common sense to answer some questions rather than knowledge and understanding. Thus, it is unclear whether improving the quality of information in health unit press releases would have greatly impacted the knowledge held by the general population. Additionally, only a small percentage of the population reported receiving information about cyanobacteria from news media, thus suggesting that even if the quality of news media information were to be improved, the number of people affected by it may be small. In summary, it may still be a useful starting point to improve the functional quality of information in health unit press releases as each was based on a pre-made template. Adding some additional information to the template could result in a reasonable increase in information distribution while requiring minimal time and money to produce.

Ultimately, it is unclear whether an individual reading an isolated news media article about cyanobacteria would have any effect on their ability to make informed health decisions. There is limited research available regarding the effects of news media on health related behaviours. This may be a valuable avenue for future research.

4.8 Future Study

The findings of this study suggest that people may have reasonably good knowledge, or possibly, the ability to make reasonably good guesses as to the safety of any given water body and recognize symptoms of cyanotoxin poisoning. However as the sample did not reflect confidence in their answers it is unclear how this could affect illness incidence. Future research could focus on what effect confidence has on illness incidence or likelihood of exposure. It would be useful to know whether people with different levels of confidence in their ability to recognize potentially dangerous blooms tend towards more cautious or reckless actions regarding cyanobacterial exposure. Future research could delve deeper into the qualitative aspect of public perceptions about cyanobacteria and potentially identify additional thought processes and pathways that contribute to an individual's decision to partake in potentially risky behaviour. This could potentially be conducted through an image based questionnaire to examine participant reactions to images of cyanoblooms in recreational water settings.

Another area of future research could examine the effect of personal stories and fear on information retention and behaviour. The research could present mock articles to participants, with one emphasizing first hand accounts of the impact of cyanoblooms, one emphasizing the health risks posed by cyanobacteria, to humans or pets, and a control article presenting the same key information but without personal stories or emotionally charged vernacular.

Another avenue of future study would be to examine the research findings through the lens of the science communication field. Determining how to effectively communicate about cyanobacteria in a way that leads to greater knowledge and better health outcomes may be an essential aspect of public health in coming years. Interdisciplinary research between public health and science communication could offer useful insights to improve information dissemination techniques and inform public health programs. This research could involve conducting focus groups with members of the public to determine what information they can absorb from current information dissemination procedures and ask for their input on how to improve the current methods. It may also be useful to incorporate materials for children to learn the signs of cyanoblooms or for parents and children to learn together given that families with children are frequent users of recreational waterways. Creating a hands-on learning experience that appeals to all ages and shows how multiple factors contribute to cyanoblooms, including eutrophication and climate change may help improve understanding and information retention and ultimately lead to better health outcomes.

Additionally, it may be beneficial to survey public health personnel who monitor recreational water quality to determine what improvements they could suggest regarding informing the public. Personnel who work in the field daily would likely be able to reveal areas that can be improved and relate common queries from the people they encounter during their work. By gathering feedback and collaborating with health unit personnel, we may gain a deeper understanding of the information needs of the community and effective ways to address them. Involving public health workers in the development of communication materials could ensure that the information is both relevant and accessible, tailored to the audience's level of understanding.

As noted by Stone and Bress, (2007) it is difficult to draw meaningful conclusions about cyanobacterial epidemiology from studies that vary significantly in context. Thus future research must focus on repeated examinations of the same populations in order to see trends that occur over time and make it possible to draw meaningful conclusions within the population.

As some time has passed since the original examination of the news media and the information supplied by the health unit press releases, a brief secondary analysis of two articles—one from 2018 (Bracebridge Examiner) and one from 2024 (Innisfil Journal)—examined changes in how health unit press releases were reported by the media. The revised coding key, focused on press release content, showed the 2018 article scored 78/100, down from its original 90/100, highlighting areas for improvement when specifically evaluating press release information. The 2024 article scored 90/100, showing improvements such as including an image of a cyanobloom, mentioning skin irritation risks, and explaining how to report blooms. However, both articles still lacked sufficient details on exposure routes, when to seek medical treatment, long-term health impacts, cyanobloom causes, and signage for swim advisories.

Providing information about these aspets in future versions of health unit press releases may improve public understanding of how to avoid cyanobacteria by ensuring that individuals are aware that dermal and inhalation exposure is possible, particularly because the guidelines do not take these exposure types into account in the proscribed limits and individuals may be accustomed to participating in non-immersive recreational water exposure during swim advisories for fecal coliforms.

Including information about when to seek medical care can illustrate both what symptom severity requires medical attention and that exposure can result severe adverse health events, which may also lead to long term illness.

Including the causes of cyanoblooms can provide information that can help identify conditions that indicate that blooms may occur. This could improve individuals' understanding of how to identify cyanoblooms, especially when engaging in recreation in areas where monitoring is not regularly performed.

Informing the public of the signage system for swim advisories could help make individuals more confident in their choice to swim during normal conditions and possibly more inclined to avoid swimming during an advisory.Additionally, as social media has become more prevalent in recent years, including the dissemination of information, from both well informed and less informed sources, it may be beneficial to examine social media postings and comments referring to cyanobacteria. Social media could present an effective means of disseminating information but may also result in misinformation being spread.

While increasing awareness may reduce the number of people who become exposed to cyanobacterial blooms, the blooms themselves are detrimental not only to human health but have a detrimental impact on wellbeing by limiting access to recreation, reducing property values, loss of revenue from tourism and fishing as well as severely impacting the environment and wildlife. Thus, future research should focus on reducing exposure to cyanoblooms and reducing the occurrence of blooms. The following section makes note of promising research in the field that requires more study:

Anantapantula and Wilson concluded through meta-analysis that most in situ treatments for cyanoblooms did not significantly improve water quality (Anantapantula and Wilson, 2024). Only four of the18 tested chemical treatments and none of the tested bacterial, physical, or plant-based treatments had significantly improved water quality (Ananpatula and Wilson, 2024). At present, nutrient management is the best long term solution (Anantapatula and Wilson, 2024) but some potential control methods are being developed which require additional research.

Most control methods focus on reducing phosphorus loads in the water but different sources of nitrogen, particularly urea, altered the toxicity levels of the cyanobacteria (Lad et al., 2022). Lad and colleagues (2022) noted that focusing control on nitrogen levels may aid in reducing the toxigenicity of blooms. This presents an avenue of future research that may result in more methods to mediate the effects of cyanoblooms. In conjunction with other control methods may help to reduce the occurrence and severity of harmful algal blooms. Some other control methods that have shown promising results have been the use of ferrate to oxidise the cyanoblooms and the toxins and *U.latuca macroalga* as a growth inhibitor (Aranda et al., 2023)

Research that has been conducted by Aranda and colleagues (2023) has begun investigating the potential for using cyanophages as a control measure for cyanobacteria that may eventually provide a means of reducing the severity and occurrence of cyanoblooms. Cyanophages are viruses that solely infect cyanobacteria and may represent a novel method to control cyanoblooms (Aranda et al., 2023). Cyanophages are typically host-specific which while preventing unintentional destruction of non target species also limits the efficacy in reducing cyanoblooms which often contain several species of cyanobacteria, though new strains may affect several cyanobacterial species (Aranda et al., 2023). Some cyanophages may infect more than one genus of cyanobacteria but cyanophages that are more host specific seem to be more virulent than those that are less host specific (Bhatt et al., 2023). Further study is needed to understand the virus and host interactions between cyanophages and cyanobacteria but there is the possibility of using cyanophages to combat cyanobacterial blooms in the future.

Monitoring cyanoblooms is necessary to provide guidance for reducing nutrient loading and early warning of reduced water quality. Sandwich hybridization assay (SHA) poses a promising method for *in-situ,* near real time detection of cyanobacteria which could improve monitoring detail and allow for more timely reactions to changing bloom dynamics (Gong et al., 2022). SHA testing does not require amplification of cell samples and can test for multiple species simultaneously while also being portable, rapid, inexpensive, and amenable to automation (Gong et al., 2022). However, SHA is semi-quantitative as it measures numbers of a target gene which does not necessarily indicate cell density in the sample and depending on the targets used it may be difficult to differentiate closely related species (Gong et al., 2022). Additionally, as SHA requires cells to be lysed to test, there is a need to find methods that can effectively lyse all of the cyanobacterial species of interest (Gong et al., 2022). More research is needed further to develop SHA as a rapid and broad monitoring method but it could greatly improve the response time to changing cyanobacterial loads in waterways.

Vaughan and colleagues posed the possibility of using artificial intelligence (AI) image recognition using machine learning to speed up analysis of water samples containing cyanobacteria by rapid classification of the cell types present (Vaughan et al., 2022). Vaughan and colleagues propose a monitoring system utilizing water sampling buoys and neural network analysis of the samples for real time water quality monitoring (Vaughan et al., 2023). Current technology and available equipment are capable of creating a monitoring buoy that could gather the samples and relay the images to a neural network, but a large data set of cyanobacterial cell images that can be used to train the neural network needs to be developed. With more study this research could potentially produce a useable prototype within the next few years.

An additional avenue of research relates not to the toxicity of cyanobacteria itself, but its role as a reservoir and disseminator of antibiotic resistance genes (Wang et al., 2024) Cyanobacteria can host antibiotic-resistant genes and there is concern that the rise in cyanoblooms and pharmaceutical pollution may promote horizontal and vertical gene transmission in cyanobacteria and other environmental bacteria though there is need for more study in this area (Volk and Lee, 2023). Antibiotic contamination of waterways even at levels that are not inhibitory can still provide enough weak selective pressure to select for more antibiotic-resistant bacteria in waterways (Wang et al., 2024) Increased temperatures accelerate the development antibiotic resistance in cyanobacteria (Wang et al., 2024). With both antibiotic resistance and cyanoblooms becoming a larger problem, additional research in the interaction between the two may be essential.

An additional branch of research concerning cyanobacterial exposure research is inhalational cyanotoxin poisoning. Inhalational cyanotoxin exposure also requires greater study as aerosols containing cyanotoxins can travel over 30km from the affected water sources and an individual may inhale over 11,000 litres of air per day on average (Lad et al., 2022). Microbes and algae ranging in size of 0.5 to 5 micrometers in size can be emitted from sea water and 10% can remain in the air for 4 days after emission and can travel up to 11000 km (Sun et al., 2023). The algal cells can then be inhaled and lodge in the nostrils and lungs in addition to the aerosolization of the cyanotoxins themselves (Sun et al., 2023). Inhalation of airborne algae and algal toxins may cause skin irritation and respiratory problems in humans (Sun et al., 2023). Inhalational intake of cyanotoxins has a lower median lethal dose than oral intake of cyanotoxin, suggesting that inhalational intake may be more dangerous than oral intake (Sun et al., 2023). Reif and colleagues (2023) noted that participants who had not interacted directly with a waterbody but lived nearby showed elevated levels of cyanotoxins in their nasal swab results and presented with respiratory symptoms. There is currently very limited research on inhalational cyanotoxin poisoning but recent literature has suggested that it may pose a significant threat to public health and more study is needed.

In addition to research into the possibility of inhalational cyanotoxin exposure as a threat to public health, there is some research that suggests that groundwater may also harbour cyanotoxins at levels sufficient to cause illness. Ground water may be contaminated with cyanotoxins when surface water containing the toxins recharge groundwater as soil is ineffective at filtering or degrading toxins (Mutoti et al., 2023). Mutoti and colleagues noted that groundwater makes up about 30% of all freshwater and in commonly extracted and used as drinking water with no treatment (Mutoti et al., 2023). There has been limited research into the amounts of cyanotoxins found in groundwater some tests have shown concentrations of cyanotoxins exceeding guidelines for safe consumption which indicates that cyanotoxins in groundwater require more research and potentially a public health response (Mutoti et al., 2023).

Additionally, while acute cyanotoxin exposure has been studied in the most common contexts, more study is needed into the long-term health effects of cyanotoxin exposure or how cyanotoxin exposure may affect those with pre-existing health conditions. Lad and colleagues (2022) note there is need to determine how pre-existing illness may affect susceptibility to cyanotoxin poisoning. Specifically, there is evidence that chronic cyanotoxin exposures that are far below the current acceptable limits can cause increased hepatic injury in individuals who have existing non-alcoholic fatty liver disease (NAFLD)(Lad et al., 2022). NAFLD affects approximately 75 to 92% of obese individuals in North America and there has been some research into the possibility that cyanotoxin exposure can contribute to the development of the disease there is minimal research into the effect of cyanotoxin exposure on those who have already developed the condition (Lad et al., 2022). Lad and colleagues (2022) noted that cyanotoxin exposure is associated with overall impaired kidney function, gastrointestinal and colorectal carcinoma, and gastroenteritis but it is unclear whether cyanotoxins were a causative factor or simply exacerbated existing conditions.

Ultimately, avoiding exposure to cyanobacteria is a temporary solution. Addressing eutrophication would not only decrease the frequency of cyanoblooms and related exposure but also reduce the environmental damage caused by these blooms. To reduce eutrophication, a collaborative effort is needed between governments, municipalities, industries, and landowners to enforce better practices in the manufacturing, disposal, and responsible use of nitrogen and phosphorus-based products. Achieving this requires effective dissemination and understanding of relevant information among all stakeholders to ensure support from the public, industry, and government.

4.9 Conclusion

This study conducted a novel examination of public perceptions of cyanobacteria that focused on ways to mitigate exposure to potentially harmful blooms. The research revealed that there is room for improvement in the news media portrayal of cyanobacterial blooms and the associated risks. These improvements must focus on giving individual members of the public the tools needed to make their own informed decisions about the safety of a water- based activity due to current available monitoring practices and the nature of cyanobloom progression. These improvements in information dissemination must also consider the changing nature of news media and information dissemination systems by providing more interactive methods of educating the public about cyanobacteria and measures that can be taken to reduce the risk of illness. It would be beneficial to give people the knowledge necessary to avoid hazardous algal blooms and enough confidence in their knowledge to use it effectively.

References

Aguilera, A., Almanza, V. Haakonsson, S., Palacio, H., Benitez Rodas, G., Barros, M., Capelo-Neto, J., Urrutia, R., Aubriot, L., and Bonilla, S. (2023) Cyanobacterial bloom monitoring and assessment in Latin America. *Harmful Algae*. 125. 102429.

Almeida, C., Gonzalez, S., Mallea, M., Gonzalez, P. (2012) A recreational water quality index using chemical, physical, and microbial parameters. *Environ Sci Pollut Res* 19: 3400 – 3411

Aranda, Y., Bhatt, P., Ates, N., Engel, B., Simsek, H. (2023) Cyanophage-cyanobacterial interactions for sustainable aquatic environment. *Environmental Research*. 229: 115728

Anantapatula, S., and Wilson A. (2024) Most treatments to control freshwater algal blooms are not effective: Meta-analysis of field experiments. *Water Research*. 243:120342

Backer, L., Manassaram-Baptiste, D., LePrell, R., Bolton, B. (2015) Environmental data from Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007 – 2011. *Toxins* 7: 1048 – 1064

Backovic, D., Tokodi, N., Nikolin, B., Svircez, Z. (2020) Cyanobacteria – insidious foe of the skin? *Journal of Water and Health* 18.3.

Bennell, M. Joyce, A., Gardner, E., Frontenac, K., Majury, A. (2015) An evaluation of Southeastern Ontario recreational water quality. *International Prespectives.* 77:10 26-33

Bertani, I., Steger, C., Obenour, D., Fahnenstiel, G., Bridgeman, T., Johengen, T., Sayers, M., Schuchman, R., Scavia, D. (2017) Tracking cyanobacterial blooms: Do different monitoring approaches tell the same story? *Science of the Total Environment* 575: 294 – 308

Bracebridge Examiner (2018) Testing confirms blue-green algae in Leonard Lake, Muskoka. https://www.muskokaregion.com/news/testing-confirms-blue-green-algae-in-leonard-lake-muskoka/article_5b5c8990-5c7e-5baf-bafa-c61f48a5b203.html?

Burnford, M., Carey, C., Hamiltion.D., Huisman, J., Paerl H., Wood, S., Wulff, A. (2020) Perspective: Advancing the research agenda for improving understanding of cyanobacteria in a future of global change. *Harmful Algae*, 91.

Chaffin, J, Westrick, J., Reitz, L., Bridgeman, T. (2023) Microcystin congeners in Lake Erie follow the seasonal pattern of nitrogen availability. *Harmful Algae*. 127

Chapra, S., Boehlert, B., Fant, C. Bierman, V., Henderson, J., Mills, D., Mas, D., Rennels, L., Jantarasami, L., Martinish, J., Strzepek, K., Paerl, H. (2017) Climate change impacts on harmful algal blooms in U.S freshwaters: a screening level assessment. *Environmental Science and Technology*

Chorus, I. and Bartram, J. (1999) Toxic cyanobacteria in water: A guide to public health consequences, monitoring and management. *E & FN Spon.* Suffolk.

Dellinger, J., Dorevitch, S., Faustman, E., Foldy, S., Takaro, T. 2017. Human health effects of cyanobacterial toxins in the great lakes region: A science and monitoring assessment. *International Joint Commission by the Health Professionals Advisory Board*

Drobac, D., Tokodi, N., Simeunovic, J., Baltic, V., Stanic, D., Svircev, Z. (2013) Human exposure to cyanotoxins and their effect on health. *Arh Hig Rada Toksikol* 64: 305 – 316

Funari, E., Manganelli, M., Buratti, F., Testai, E. (2017) Cyanobacteria blooms in water: Italian guidelines to assess and manage the risk associated to bathing and recreational activities. *Science of the Total Environment* 598: 867 – 880

Gaget, V., Almuhtaram, H., Kibuye, F., Hobson, P., Zamyadi, A., Wert, E., Brookes, J. (2022) Benthic Cyanobacteria: A utility-centered field Study. *Harmful Algae*. 133.

Gong, P., Antrim, A., Bickman, S., Cooley, E., Chung, S. (2022) Sandwich hybridization assay for in situ real time cyanobacterial detection and monitoring: A review. *Biosensors*. 12:640

Health Canada (2012) Guidelines for Canadian Recreational Water Quality, Third edition. Water, Air, and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Howard, M., Kudela, R., Hayashi, K., Tatters, A., Caron, D., Theroux, S., Oehrle, S., Roethler, M., Donovan, A., Loftin, K., Laughrey, Z. (2021) Multiple co-occuring and persistently detected cyanotoxins and associated cyanobacteria in adjacent California lakes. *Toxicon*

Huisman, J., Codd, G., Paerl, H., Ibelings, B., Verspagen, J., Visser, P. (2018) Cyanobacterial Blooms. *Nature Reviews: Microbiology*. 16.471.

Innisfil Journal (2024) Blue-green algae confirmed in Innisfil waters, Simcoe Muskoka District Health Unit says. https://www.simcoe.com/news/blue-green-algae-confirmed-in-innisfil-waters-simcoe-muskoka-district-health-unit-says/article_508f1c45-fec8-5aff-b40a-979a25101c7d.html

Kaloudis, T., Hiskia, A., Triantis, T. (2022) Cyanotoxins in bloom: Ever-increasing occurrence and global distribution of freshwater cyanotoxins from planktic and benthic cyanobacteria. *Toxins*. 14:264

Lad, A., Breidenbach, J., Su, R., Murray, J., Kuang, R., Mascarenhas, A., Najjar, J., Patel, S., Hegde, P., Youssef, M., Breuler, J., Kleinhenz, A., Ault, A., Westrick, J., Modyanov, N., Kennedy, D., Haller, S. (2022). As we drink and breathe: Adverse health effects of microcystins and other harmful algal bloom toxins in the liver, gut, lungs, and beyond. *Life*. 12:48

Lee, T., Rollwagen-Bollens, G., Bollens, S., Faber-Hammond, J. (2015) Environmental influence of cyanobacteria abundance and microcystin toxin production in a shallow temperate lake. *Ecotoxicology and Environmental Safety* 114: 318 – 325

Lin, C., Wade, T., Sams, E., Dufour, A., Chapman, A., Hilborn, E. (2016) A prospective study of marine phytoplankton and reported illness among recreational beachgoers in Peurto Rico, 2009. *Environ Health Perspect* 124:477-483

McGregor, G., Stewart, I., Sendall, B., Sadler, R., Reardon, K., Carter, S., Wruck, D., Wickramasinghe, W. (2012) First report of a toxin *Nodularia spumingena* (Nostocales/cyanobacteria) bloom in sub-tropical Australia.I phycological and public health investigations. *Int. J. Environ. Res. Public Health* 9: 2396 - 2411

Metcalf. J., Codd, G. (2020) Co-Occurrence of cyanobacteria and cyanotoxins with other environmental health hazards: Impacts and implications. *Toxins.* 12, 629.

Mishra, S., Stumpf, R., Schaeffer, B., Werdell, J., (2023) Recent changes in cyanobateria algal bloom magnitude in large lakes across the contiguous United States. *Science of the Total Environment*. 897:165253.

Mutoti, M., Edokpayi, J., Mutileni, N., Durowoju, O., Munyai, F. (2023) Cyanotoxins in groundwater; occurrence, potential sources, health impacts, and knowledge gap for public health. *Toxicon.* 226; 107077

Nielsen, M., Jiang, S. (2020) Can cyanotoxins penetrate human skin during water recreation to cause negative health effects? *Harmful Algae*. 98

Osborne, N., Shaw, G., Webb, P. (2006) Health effects of recreational exposure to Moreton Bay, Australia waters during a *Lynbya majuscula* bloom. *Environment International* 33 309 – 314.

Otten, T. and Paerl, H. (2015) Health effects of toxic cyanobacteria in U.S. drinking and recreational waters: Our current understanding and proposed direction. *Current Environmental Health Reports* 2: 75 -84

Pinto, A., Botelho, M., Churro, C., Asselman, J., Pereira, P., Pereira, J. (2023) A review on aquatic toxins – Do we really know it all regarding the environmental risk posed by phytoplankton neurotoxins? *Journal of Environmental Management*. 345; 118769

Plaas, H., Paerl, H. (2021) Toxic cyanobacteria: A growing threat to water and air quality. *Environmental Science and Technology*. 55, 44-64.

Persuad, A., Paterson, A., Dillon, P., Winter, J., Palmer, M., Somers, K. (2015) Forecasting cyanobacterial dominance in Canadian temperate lakes. *Journal of Environmental Management* 151: 343 – 352

Rastogi, R., Madamwar, D., Incharoensakdi, A. (2015) Bloom dynamics of cyanobacteria and their toxins: Environmental health impacts and mitigation strategies. *Frontiers in Microbiology* 6: 1254

Reif, J., Stockley, N., Harvey, K., McFarland, M.,Gordon, S., Schaefer, A. (2023) Symptom frequency and exposure to a cyanobacteria bloom in Florida. *Harmful Algae*. 129: 102526

Schafer. A., Yrastorza, L., Stockley, N., Harvey, K., Harris, N., Grady, R., Sullivan, J., McFarland, M., Reif, J. (2020) Exposure to microcystin among coastal residents during a cyanobacteria bloom in Florida. *Harmful Algae*. 92

Stewart, I., Webb, P., Schluter, P., Shaw, G. (2006 A) Recreational and occupational field exposure to freshwater cyanobacteria – a review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. *Environmental Health: A Global Access Science Source* 5:6.

Stewart, I., Webb, P., Schluter, J. Fleming, L., Burns, J., Gantar, M., Backer, L., Shaw, G. (2006 B) Epidemiology of recreational exposure to freshwater cyanobacteria – and international prospective cohort study. *BioMed Central Public Health* 6:93.

Sun, Y., Guo, Y., Xu, C., Liu, Y., Zhao, X., Liu, Q., Jeppesen, E., Wang, H., Xie, P. (2023) Will "air eutrophication" increase risk of ecological threat to public health*? Environmental Science and Technology*. 57:10512-10520.

Svircev, Z., Drobac, D., Tokodi, N., Vidovic, M., Simeunovic, J., Milandinov-Mikov, M., Baltic, V. (2013) Cancer in Serbia and possible connection with cyanobacterial blooms. *Journal of Environmental Science and Health,* Part C, 31:181 – 200.

Van de Waal, D., Gsell, A., Harris, T., Paerl, H., de Sederpont Domis, L., Huisman, J. (2024) Hot summers raise public awareness of toxic cyanobacterial blooms. *Water Research*. 249:120817.

Vaughan, L., Zamyadi, A., Ajjampur, S., Almutaram, H., Freguia, S. (2022) A review of microscopic cell imaging and neural network recognition for synergistic cyanobacteria identification and enumeration. *Analytical Sciences* 38:261-279

Vidal, F., Sedan, D., D'Agostino, D., Cavalieri, M., Mullen, E., Parot Varela, M., Flores, C., Caixach, J., Andrinolo, D. (2017) Recreational exposure during algal bloom in Carrasco Beach, Uraguay: A liver failure case report. *Toxins.* 9:267

Volk, A., Lee, J. (2023) Cyanobacterial blooms: A player in freshwater environmental resistome with public health relevance*? Environmental Research*. 216:114612

Wang,Z., Chen, Q., Zhang, J., Xu, H., Miao, L., Zhang, T., Liu, D., Yan, H., Yan, D. (2024) Climate warming promotes collateral antibiotic resistant development in cyanobacteria. *Water Research*. 256:121642

Watson, S., Zastepa, A., Boyer, G., Matthews, E. (2017) Agal bloom response and risk management: on site response tools. *Toxicon.* 129.

Whitman, P., Schaeffer, B., Salls, W., Coffer, M., Mishra, S., Seegers, B., Loftin, K., Stumpf, R., Werdell, J. (2022) A validation of satellite derived cyanobacteria detections with state reported events and recreation advisories across U.S. lakes. *Harmful Algae.* 115:102191

(WHO) World Health Organization (2003) Guidelines for safe recreational water environments. Volume 1: Coastal and fresh waters. Geneva, Switzerland.

Wood, R. (2016) Acute animal and human poisonings from cyanotoxin exposure – A review of the literature. *Environment International* 91:276-282

Appendices

Appendix A News Media Evaluation Coding

News Media Evaluation Coding Results

Content Evaluated: Did the Article Provide Information on:	Yes (n and %)	No (n and %)	Missing (n and %)
Content from Simcoe/Muskoka	30	69	1
Content Outside Simcoe/Muskoka	75	24	1
Symptoms of Cyanobacterial Exposure	46	54	0
Notices Will be Posted	25	74	1
Routes of Exposure	40	60	0
How to Avoid Contact with Cyanobacteria	49	50	1
When Medical Attention Should be Sought Out	11	87	2
At Home Treatment Options	12	88	2
Possible Long Term Health Effects	6	94	0
Further Information Link	22	77	1
Contact Information for Further Info	24	73	3
Contact Information to Report Suspected Bloom	13	87	0
How to Identify Cyanoblooms	33	66	1
Where Cyanoblooms can be Found in Ontario	47	52	1
Use and Effects of Algaecide	5	95	0
How Cyanobloom Occurrences can be Reduced	24	76	0
Causes and Contributing Factors to Cyanoblooms	38	62	0
Environmental Impact of Cyanoblooms	17	83	0
Paraphrase of Health Unit Press Release	49	51	0
More Info than Standard Press Release	51	49	0
Interview with Expert	45	54	1
Image of Bloom	61	38	1
Erroneous Information	3	97	0

This table shows the direct numerical results of the evaluations. The numbers represent both the n and the percent of the sample because the sample contained 100 articles.

Appendix B Survey and Consent

Survey of Blue-Green Algae and Recreation in Simcoe Muskoka Waterways

By completing and submitting this survey you consent to your responses being used in research that may be used to improve public health practices.
You may choose to stop the survey at any time and your information will not be kept.
You will not be asked for any information that could be used to identify you.
All of your responses will remain anonymous
The data from this survey will be kept on a secure Laurentian University server for a period of five years after which it will be destroyed.

If you have any questions please contact lead investigator Kristyn Madrick at blue.green.water.study@gmail.com

Study supervised by Laurentian University 935 Ramsey Lake Rd. Sudbury, ON P3E 2C6 Dr. Nancy Lightfoot. Contact at nlightfoot@laurentian.ca or by phone at: 705-675-1151 ext. 3972

If you have any concerns about this research please contact the Laurentian University Research Ethics Board at Research Ethics Officer, Laurentian University Research Office, telephone: 705-675-1151 ext 3213, 2436 or toll free at 1-800-461-4030 or email ethics@laurentian.ca.

Thank you for your participation

Do you participate in any activities in or around natural waterways (beaches, ponds, rivers) in the Simcoe/Muskoka area?

- **Yes**
- **No**

What water based recreational activities do you participate in in Simcoe/Muskoka waterbodies, if any? (Check all that apply)

- Swimming
- Wading
- Surfing
- Parasailing
- Canoeing
- Kayaking
- Fishing
- Water skiing
- Paddle Boating
- Snorkeling

- Other - Please list ________________________
- None

How frequently do you engage in recreational water activities in Simcoe/Muskoka waterways in an average summer season? Please list average number of days per summer season

______

What types of waterways do you typically go to for recreational water activities? (Check all that apply)

- Supervised Public swimming areas (Designated swimming areas with a place for a life guard to supervise swimmers)
- Unsupervised Public swimming areas (Swimming areas without any life guard supervision)
- Privately Managed swimming areas (Resort beaches)
- Private Unmanaged Swimming Areas (Privately owned beach front, river, pond, etc.)
- Unknown

Please indicate the name of the beach, swimming area, or water body that you most frequently visit for recreation. Please include the name of the town, the name of the waterbody, and the name of the swimming area/park/beach if known

Town/City ____

Water Body ____

Beach/Park/Swimming Area ____

Have you ever become ill after recreation in a Simcoe/Muskoka waterbody?

- Yes
- No
- Don’t know

If you have become ill after recreation in a Simcoe/Muskoka waterbody did you seek medical care?

- Yes
- No
- Don’t know
- Not applicable

If you did become ill after recreation in a Simcoe/Muskoka waterbody what symptoms did you have?

- Skin irritation or rash

- Earache
- Headache
- Sinus irritation
- Upset stomach
- Nausea
- Diarrhea
- Dizziness
- Eye irritation
- Coughing
- Vomiting
- Other (please specify):____
- Don't Know
- Not applicable

How concerned, if at all, are you about the safety and water quality of Simcoe/Muskoka waterways for recreational purposes (Circle one)

Unconcerned	Slightly Concerned	Somewhat Concerned	Fairly Concerned	Very Concerned
1	**2**	**3**	**4**	**5**

How concerned, if at all, are you about the safety and water quality of Simcoe/Muskoka waterbodies for drinking water purposes? (Circle One)

Unconcerned	Slightly Concerned	Somewhat Concerned	Fairly Concerned	Very Concerned
1	**2**	**3**	**4**	**5**

How concerned, if at all, are you about the safety and water quality of Simcoe/Muskoka waterways from an environmental standpoint? (Circle One)

Unconcerned	Slightly Concerned	Somewhat Concerned	Fairly Concerned	Very Concerned
1	**2**	**3**	**4**	**5**

Where do you typically get information on whether natural water bodies are suitable for swimming? (Check all that Apply)

- News Media (Television, Newspaper, Internet news sites)
- Public Beach Postings (signage posted at the location)
- Health Unit of Simcoe Muskoka Website or media
- Word of mouth
- Social Media
- Other Source* Please list ______________________________
- I do not receive information about whether natural water bodies are suitable for swimming

How concerned, if at all, are you about each of these specific potential health and safety risks of recreational water use:				
Bacteria (E. coli)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Waves (Wave height, undertow, current speed, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Beach Substrate (Sandy, Muddy, rocky, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Water clarity (Clear, cloudy, dark coloured, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Blue-Green Algae (Cyanobacteria, Toxic Algae Blooms)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Aquatic Plant Density (Sea weed, cat tails, lilies, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Garbage (plastic bags, food wrappers, aluminum cans, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Hazardous waste (hypodermic needles, broken glass, gasoline, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Biological Waste (dead animals, animal waste, used condoms, sewage, etc.)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5
Other (specify: ________________________________)				
Unconcerned 1	Slightly Concerned 2	Somewhat Concerned 3	Fairly Concerned 4	Very Concerned 5

Please read each statement carefully and indicate to the best of your knowledge whether it is true or false.

True or False: Toxic Blue-Green Algae (Cyanobacteria) blooms can and have occurred in the Simcoe/Muskoka area.

True or False: All blue-green algae blooms are toxic

True or False: Blue-Green algae can only make you sick if you swallow it or get it in your eyes, ears or nose.

True or False: It is safe to swim near a blue-green algae bloom if you don't swallow any water or get any of the algae on your skin.

True or False: Killing blue-green algae with an algaecide makes the water safe to swim in.

True or False: Exposure to blue-green algae can cause liver damage and even be a contributing cause of cancer

Do you know what symptoms exposure to blue-green algae can cause?
Exposure to blue-green algae can cause symptoms of: (Check all that apply)

- Headache
- Nausea
- Muscle tremors
- Vision loss
- Rashes or skin irritation
- Diarrhea
- Fever
- Coughing
- Vomiting
- Hair loss
- Pink eye
- Ear infection
- Liver damage
- Dry mouth
- Other (specify)

In what types of waterbodies would you look for a blue-green algae bloom (indicate all that apply)?

- Streams

- Ponds
- Rivers
- Lakes
- Oceans
- Swamps
- Ditches with standing water
- Storm water retention ponds
- I would not look for a blue-green algae bloom

What signs would you look for to determine if a blue-green algae bloom is present (indicate all that apply)?

- Clear green coloured water
- Milky green water
- Clumps of floating scum
- Paint-like surface scum
- Cloudy water
- Dead fish or other aquatic organisms
- Dark coloured water
- Foam on the water surface or on the beach
- Other (please specify):____

Please rate your level of confidence in your ability to identify a potentially hazardous blue-green algae bloom?

- No Confidence
- Minimal Confidence
- Some Confidence
- Good Confidence
- Excellent Confidence

How would you identify a potentially hazardous algal bloom? Describe what signs you would look for and what factors you would take into account.

____
____
____
____
____
____

If you see a potentially hazardous algal bloom in a Simcoe/Muskoka waterbody who should you notify?

- The Health Unit
- The police
- The media
- The municipality
- The property owner/manager
- Spills Action Center
- Other (please specify): ____
- No one

At what time of the year are blue-green algae blooms most likely to occur in Simcoe/Muskoka waterbodies?

- April – June
- July - October
- October - December
- January – March

Please describe what factors you would look for to determine whether a water body is safe for recreational activities

____
____
____
____
____
____

What do you think of engaging in recreational activities in the water during a swim advisory?

____
____
____
____
____
____
____

How likely are you personally to engage in recreational activities in the water if the location is under a swim advisory?

Not at all	Unlikely	Possibly	Somewhat Likely	Very Likely
1	2	3	4	5

Why do you engage in recreational water activities?

____
____
____
____
____
____
____

If there were a blue-green algae bloom in your area how would you want to be informed? (Signage at the beach, local news bulletins, social media, email lists, etc.)

____
____
____
____
____
____

Please indicate your age in years

- ________________

Please indicate your gender

- Male
- Female
- Other

In what city or town is your primary residence located?

____

Appendix C Ethics Certificate

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL / New X / Modifications to project / Time extension	
Name of Principal Investigator and school/department	Kristyn Madrick, M Sc program in Interdisciplinary Health, supervisor Nancy Lightfoot, CRaNHR
Title of Project	Knowledge, Attitudes, and Awareness of Health Risks of Cyanobacteria Exposure in Central Ontario
REB file number	6013940
Date of original approval of project	August 20th, 2018
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on: *(You may request an extension)*	August 20th, 2019
Conditions placed on project	

During the course of your research, no deviations from, or changes to, the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please refer to the Research Ethics website to complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate LU REB form. In all cases, please ensure that your research complies with Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations and best wishes in conducting your research.

Rosanna Langer, PHD, Chair, *Laurentian University Research Ethics Board*